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Producer-Gas on Dairy Farms.

M. Cullity, Superintendent of Dairying.

It is pleasing to see in various parts of the south-western districts the endeavours which farmers are making to overcome the difficulties caused by the rationing of petrol. The efforts of Messrs. A. H. Noon of Katterup and J. T. N. Downes of Northcliffe are particularly interesting, showing how the use of producer gas may enable the ordinary operations connected with the farm to be continued.

The following descriptions are given for the benefit of other farmers :—

Mr. A. H. Noon writes :

This producer was built as an experiment with light steel drums, with the intention, if it proved a success, to replace it with heavier welded steel plate. However, apparently owing to the small size of the fire involved, the generator never gets hot and evidently will last for a number of years.

The engine is a 3 h.p. Bamford and is used for pumping water and generating current for electric light and charging, but could be used to do other jobs requiring 2 h.p. which is about the power developed on gas. The cross-draught system is used in the generator which is a 15-gallon drum fitted with a camp oven lid.

The diameter of the tuyere proved to be the most critical item in a producer of this size. Half-inch water pipe embedded in firebrick allows too much air into the fire and it is necessary, after the blower has built up a good fire, to insert a short piece of ⅜ inch pipe inside the ½ inch pipe to act as a reducing nozzle and restrict the air.

A 1½ inch pipe connects the generator to the single scrubber which is a multi-stage arrangement. A mechanical dry-cleaner was tried next to the generator but proved unnecessary as the small suction produced by the engine is insufficient to draw anything heavier than fine dust from the producer.

The cleaner used has successive layers of fine washed gravel, washed charcoal sieved to about ¼ inch size, oiled horse-hair, two thicknesses of felt and a security filter of silk and wadding. Each layer is separated by a disc of galvanised fly-gauze, the gravel acting as a spark arrestor.

In practice the dust does not get past the bottom half of the oiled horsehair layer which is 10 inches thick, and is such a small deposit that cleaning out the scrubber is necessary only at infrequent intervals.

A blower is almost indispensable with a producer of this size, as if the engine is started with petrol a certain amount of air must be admitted to burn with it and this leaves such a small suction available for the producer that it usually takes at least ¼ hour to build up a fire sufficient for a changeover. An electric blower was made for this outfit from a large horn motor, and casing and rotor of 22 gauge galvanised iron.

Quality of charcoal is very important. The engine will start on gas, without using petrol, in 3 minutes with good whitegum charcoal—jarrah and blackbutt products take longer.

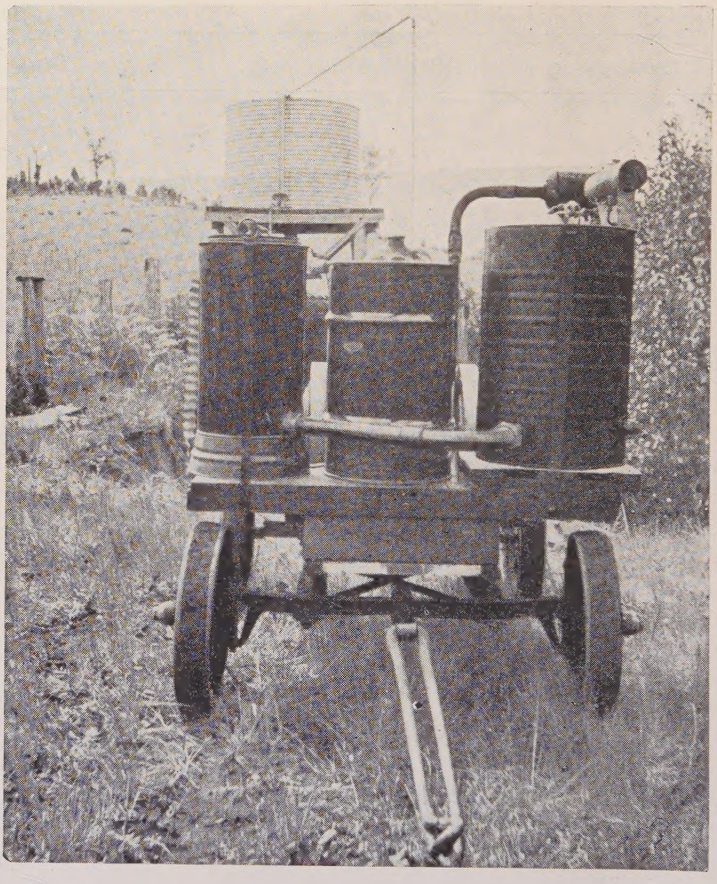

Fig. 1

In fig. 1 of the front of the producer the left hand drum is the scrubber, the centre one the engine water cooling tank and the right hand one the generator on top of which can be seen the water drip feed arrangement—a brass cylinder with copper ends soldered on providing a rustless water tank and small needle valve tap attached.

This feeds into the air intake (see fig. 2), a ½ inch pipe running from the top of the producer, down along the inside wall to within 6 inches of the bottom and is screwed into an inverted tee. Into one side of this is screwed 4 inches of pipe which is surrounded by firebrick and forms the tuyere and the other side is extended through the wall and fitted with a socket and plug.

This plug is removed to insert the reducing nozzle mentioned and also to light the fire, which is accomplished in a few seconds by pushing a piece of lighted, kerosene soaked twine into the tuyere with the blower running.

The blower can be seen close to the carburettor from which position it draws the gas through the system to the engine.

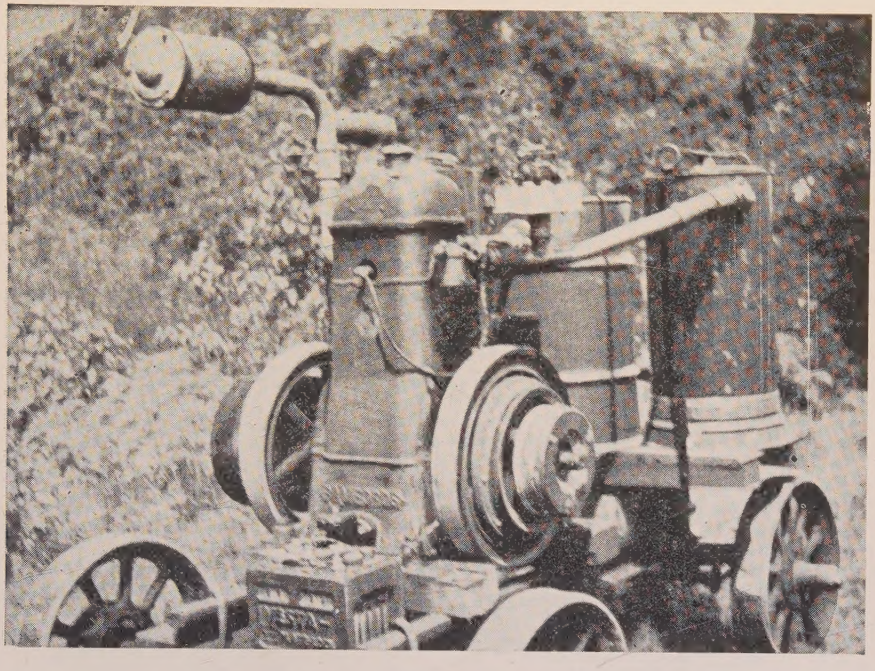

Fig. 2.

The whole is mounted on a transport made from two pieces of rail bearers, a T Ford front axle assembly with 15 inches of centre removed and halves welded together again for narrowing the track, and two Ford rear axles welded together for the back axle. On these are fitted four steel Fiat car wheels.

Mr. J. T. N. Downes has supplied the following information per Dairy Adviser J. T. McNally :

Before the institution of petrol rationing, Mr. Downes anticipated considerable difficulty in procuring sufficient fuel to enable him to operate his conveyance and his milking machine engine as previously. His first decision was to purchase a gas producer to be fitted to his Pontiac utility truck. With his son he then considered whether the producer gas could be utilised for driving the milking machine engine. Eventually they devised a method of linking the gas producer to the engine which has proved highly successful. The milking machine is a 4-unit " Perfect " and a 75-gallon McCormack Deering separator is also installed and driven by the engine which is a 3-horse power Lister.

By making this arrangement the petrol consumption for the work of milking the 30 cows has been reduced from nine to one and a half gallons per month. Naturally there is also a considerable saving in cash as petrol costs approximately 3s. per gallon in Northcliffe and all the charcoal for the generator is prepared on the property. Milking time occupies 14 hours weekly and one bag of charcoal is used in that time.

The engine is started on petrol but only for a short period, at most two minutes, when the petrol is gradually shut off and the gas turned on.

The engine is usually running on gas within ten minutes of lighting the fire in the generator. The engine is allowed to run for about five minutes on gas before the load is taken up. Therefore only 15 minutes passes between the lighting of the fire and the commencement of milking. In this time the sundry odd jobs in preparing the machine and utensils can receive attention and so actually no time is lost.

The method used for linking the engine and producer is shown in Figures 3 and 4.

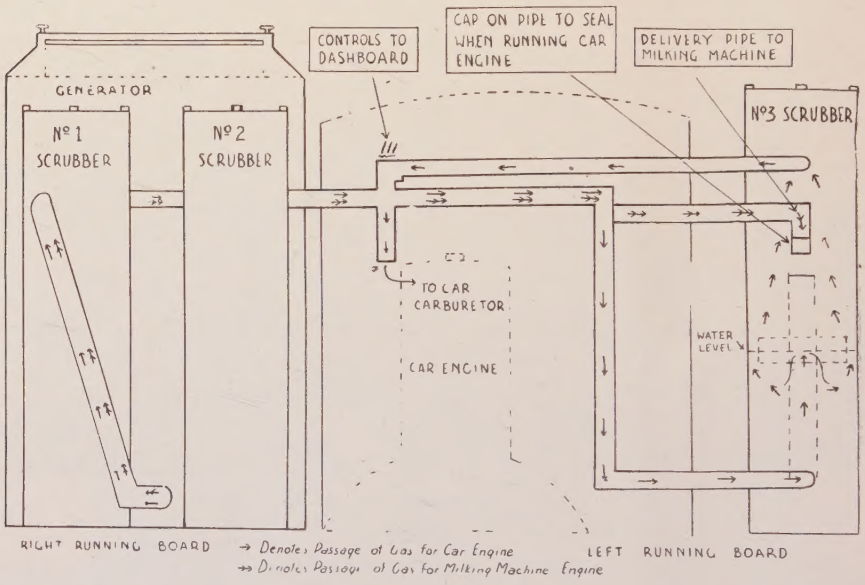
CONTROLS TO DASHBOARD
CAP ON PIPE TO SEAL WHEN RUNNING CAR ENGINE
DELIVERY PIPE TO MILKING MACHINE
GENERATOR
No 1 SCRUBBER
No 2 SCRUBBER
No 3 SCRUBBER
TO CAR CARBURETOR
CAR ENGINE
WATER LEVEL
RIGHT RUNNING BOARD
→ Denotes Passage of Gas for Car Engine
⇒ Denotes Passage of Gas for Milking Machine Engine
LEFT RUNNING BOARD

Fig. 3

The utility after use for cartage or other purposes is driven to the shed into a marked position from which the gas leads on the producer can be connected directly to the stationary engine.

A special lead is taken from No. 2 scrubber with connections of rubber hose to allow for small variations in the position of the utility truck. This lead is closed with a cap, when the car engine is required and the gas is diverted through No. 3 scrubber before being introduced into that engine. It was found that the small stationary engine could not draw sufficient gas through the 3 scrubbers and accordingly the most difficult, the third or water scrubber, was short circuited by the gas delivery pipe to this small engine. A further cleaner packed with sisal hemp was fitted in this pipe line—Figure 4.

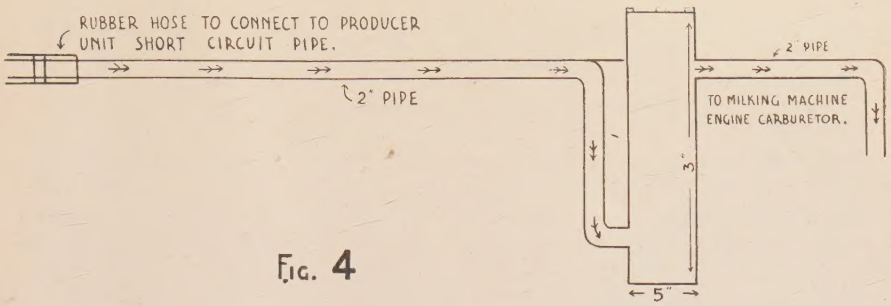

FIG. 4

In preparing to start the engine a blower is fitted to the gas delivery pipe before connection is made to the engine. This blower, made from an old car horn motor, is driven by electricity from the car battery and is allowed to operate while the generator is being fired and for the period until the delivery pipe is connected.

The engine is then running on petrol and the change over to gas occupies less than two minutes.

The gas then passes direct to the engine through this pipe and sisal hemp cleaner, the whole bridging the space of 15 feet between the gas generator and the engine. The pipes are 2 in. in diameter ; at the carburetter a reduction to $\frac{3}{4}$ in. is made. A special fitting is used, which has a rectangular opening and delivers gas directly into the manifold of the engine. A slide valve is fitted before the reducing piece to control the flow of gas.

The only alteration in the operation of the furnace which has been found necessary is in the size of the charcoal which has been found to be best when $\frac{3}{4}$ in. to 1 in. in diameter. Larger sizes are found quite suitable for the operation of the car engine.

The plant has now been in operation for more than six months and has given excellent service.

The engine was dismantled after three months' running and it was then stated that the cylinder head and valves and bearings were in excellent condition.

Employers!

The Chief Inspector of Factories (Mr. F. W. Warman) desires to draw the attention of all employers to the requirements of section 10 of the Workers' Compensation Act, 1912–1939. This section makes it obligatory for every employer to obtain from an approved insurance office a policy of insurance for the full amount of the liability to pay compensation under the Workers' Compensation Act, 1912–1939, to all workers employed by him.

Investigations have revealed that quite an appreciable number of employers have failed to comply with the above and have thereby committed a very serious offence against the Act.

To avoid the need for drastic departmental action employers are advised to check up on their own position and, if not already in possession of the necessary policy, to obtain cover without further delay.

Reconditioning an Apiary.

L. Blair, Apiculturist.

To be profitable, like any other stock, bees require a certain amount of attention. Without this they degenerate into something that pays no dividends, and becomes a burden to the owner. They are a menace to his neighbours and a source of potential disease to the commercial apiarist who may visit the district periodically.

The following will show how simple it is to convert a number of colonies of bees from a non-paying to a profitable basis without much expense, but a fair amount of application and work.

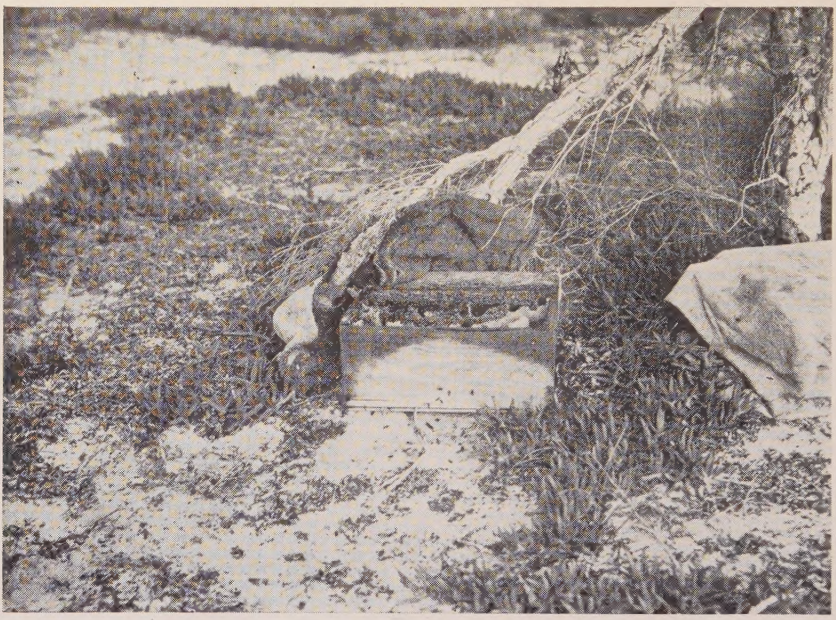

Fig. 1.
Fruit-case bee hives or nests with bag covering lifted on one to show comb and bees.

The above depicts two colonies of bees housed in the very familiar fruit case. The bag acting as a lid or roof for these bees has been lifted up showing the comb and bees. The difficulty of manipulating this kind of hive for any profit to the owner or benefit to the State is obvious.

Figure 2 shows a similar arrangement with a different foundation. This bee home consists of an old fashioned iron clothes trunk and would be extremely uncomfortable to the inhabitants in either extremes of weather. When the covering is raised the bees and comb can be clearly seen. Despite the drawback of their accommodation, the bees are still working hard to provide for the future. The majority of the colonies in this apiary, which numbered about 90, were mostly in fruit cases and no real protection was provided for them. This left little or no prospect of getting the best returns from them.

Fig. 2.
Iron clothes trunk bee nest. Note bees and comb attached to lid which was also covered by bag.

The 44-gallon drum in the next figure was sheltering a vigorous colony as can be seen by the number of bees clustering among the combs. This home gave the bees plenty of room for expansion in comparison with the previous illustrations where they were confined to fruit cases.

Not only was good revenue being lost from these sources, but there was also the danger of losing all these colonies by bush or grass fires which are very prevalent in most districts in the hot weather. In considering this danger it is always advisable to have fire breaks in the apiary, one of about 6 ft. to 8 ft. wide completely encircling it and the second of about 18 ins. wide around each individual hive. This additional protection also adds to the comfort of the operator when inspecting or working with the bees in any seasonal operations.

Apart from this danger there is the one of disease to consider, and this would be extremely difficult to control in such an apiary. With bees labouring under such conditions disease would most likely obtain a big hold and claim the greatest number of the colonies as victims before the danger was discovered. The hives could not be examined thoroughly without cutting out some of the outside combs. It is very necessary to examine them periodically if one wishes to find and eradicate any disease in the early stages, which is the economically sound time. The diseases that are most dangerous to the West Australian apiarists are Brood Diseases (American Foul Brood, *Bacillus larvae;* European Foul Brood, *Bacillus alvei*).

In many cases the beekeepers have blamed the seasons and many other causes for their bees dying out with disease, when they were spreading the infection themselves by placing the supers and frames from infected hives on top of strong colonies to save the combs from the ravages of Wax Moth. Such practices constitute a grave menace to all other beekeepers in the district.

Should there be doubt about the disease in question, the apiarist should cut a piece of affected brood comb about three or four inches square and forward it to the Department. This should be well wrapped to avoid breakage. It can then be examined, a diagnosis made, and treatment advised. This may result in the saving of a considerable number of hives as well as the eradication of the disease in question.

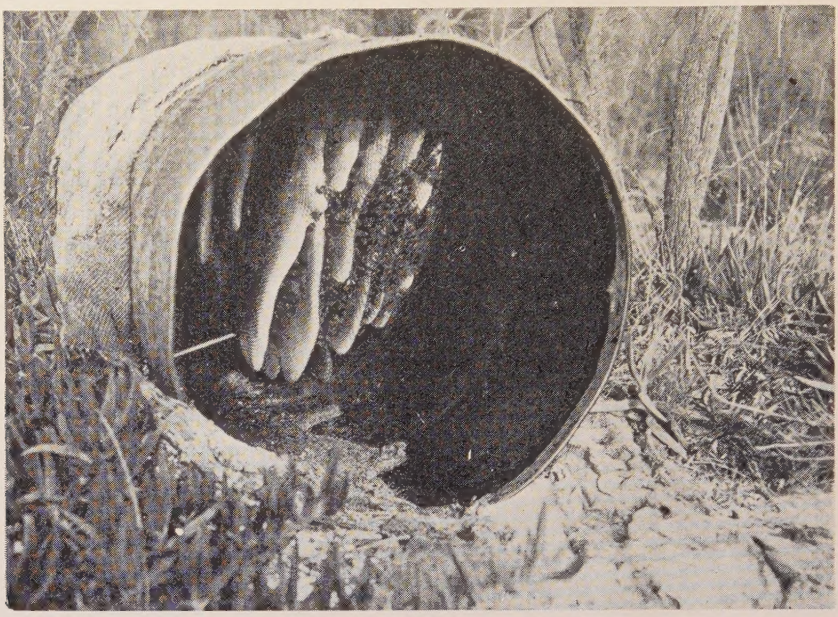

Fig. 3.
A 44-gallon oil drum used by this colony as a home. Bee-comb melted by hot weather can be seen on the bottom of the drum.

The following figure (4) shows a hive that has died out or been deserted by the bees for some reason or other—this may have been starvation, ants, disease, failure of the young queen to be mated, or to return from her wedding flight, or any other cause. The main fact is that the Wax Moths have moved in, taken possession and left it in a very sorry condition. This occurs through pure neglect, for with ordinary care the cause can be noted and corrected. Another point in this case is the great difficulty in arriving at a conclusion for the desertion by or dying out of the colony. If disease were the cause, the Wax Moth in a very short period would have destroyed all visible evidence, but, unfortunately, they would not destroy the spores or seeds of the disease.

Before the comb is destroyed by Wax Moth, supposing the hive had died of disease, there would be evidence left in the brood cells in the shape of dead bees or larvae, shrunken and lying on the bottom of the cell. These remains, in the case of American Foul Brood, are very difficult to remove. When riddled and eaten by Wax Moths the visible evidence would be lost, unfortunately, however, the Wax Moth would not be a blessing in disguise and remove all the danger of infection from the diseased hive and frames. Subjecting the scrapings of the hive parts and the residue to a detailed microscopical examination would then be necessary before a correct conclusion could be arrived at as to why the hive died out. In such cases it would be much safer to burn the moth-riddled hive complete than use it again.

If the hive is in good order otherwise and the rest of the apiary perfectly clean, it would be perfectly safe to use it after soaking the parts in a solution of 80 parts water and 20 parts formalin for 48 hours. Another alternative would be scorching the inside of the hive to a rich brown *after removing the metal*

Fig. 4.
Frame riddled by wax moth. Remains of other frames in foreground are from the same hive.

rabetts. There are several methods of doing this, and the following two are effective: To go over the whole of the inside surface with the flame of a painter's blow-lamp or to place three or four hive bodies on top of each other, the bottom body raised from the ground on bricks; paint the insides thoroughly with kerosene and ignite the bottom one. The scorching must be done completely as the germ spores are difficult to eradicate. Any omission at this stage would leave the hives in the position of being the cause of another outbreak of disease. Any material severely cracked should be burnt. The first loss is the cheapest in the long run.

Figure 5 gives a view of one part of this apiary mostly housing strong colonies of bees in many varied types of boxes and cases, in fact anything in which the bees would stay. This shows the tolerance of these wonderful little workers to more or less adverse living conditions. The annual production of this apiary in this condition was practically nil, or perhaps supplied the owners with a little honey-comb for personal use. The total value of this apiary and equipment in this condition would not exceed £10-£15.

Fig. 5.
The apiary site as it was originally.

Upon inspection, however, it was pointed out to the owners the advantage that would accrue from placing the apiary and plant in good order. This was done. Packing cases were purchased and sawn into correct sizes and new hives

Fig. 6.
View of the frame hives in position. Contrast this with previous illustration.

made. The bees were transferred into these new homes. This transformation increased the value of this apiary from £10-£15 to one of £75-£100, with an annual output of a similar value in honey and beeswax.

A small outlay in cash and a fair amount of labour with the desire to place an undeveloped asset on the farm on a payable basis produced the result depicted in Figure 6.

The complete apiary is shown herewith with a little of the rubbish on the left hand side from their old homes. The honey and beeswax from the first year's operations after the change more than paid for the cost of materials and labour.

Fig. 7.
The completed apiary.

This clearly demonstrates what can be done with bees when treated, housed and attended to at the right time in the correct manner.

Some Light on the Sprouting of Seed Potatoes.

E. T. MORGAN,

Officer-in-Charge, Potato Branch.

It will have been noted by many growers of potatoes that where tubers have been stored for some time and are reaching the sprouting stage that injured and severe scab-affected potatoes are inclined to "shoot" before those that are not so affected. The cutting of potatoes into sets for planting induces quicker sprouting and where cut sets and "round" seed, from the same crop, have been planted at the same time the emergence of growth has been in favour of the "cut" seed by from seven to 12 days.

Research work carried out by Norwood C. Thornton and published in the Contributions from the Boyce Thompson Institute, Vol. 10, 1939, has thrown considerable light on the subject. This article quotes, "The generally accepted explanation of the inability of freshly harvested potato tubers to sprout when re-

planted at once after harvest is that the buds do not get enough oxygen from the air, that the peel is at first impermeable to this gas; and that germination of buds becomes possible only later when the peel becomes more permeable and permits the entrance into the tuber of a sufficient supply of oxygen. The corollary to this view is that the normal oxygen content of the air (20 per cent.) would be sufficient and possibly the optimum for germination if the buds could get it.

"The present paper shows that the failure of the potato buds to grow is due to the oxygen content of the air being too high, not too low, and that growth can be initiated at once, if the oxygen concentration is reduced from 20 per cent. (normal) to approximately two to 10 per cent., and further, that the peel of the freshly harvested tubers is not impermeable to oxygen, but is, in fact, more permeable at that time than at any later stage, that its permeability decreases, not increases with time until a point is reached at which the supply of oxygen to the buds has been reduced to furnish these low concentrations which are required for sprouting to proceed.

"The young tuber has no membrane that will inhibit the passage of oxygen and it is not until the later stages of its life span that the skin becomes dense, more cells are present and the cell walls become thicker. The natural growth of this membrane to a point at which entrance of oxygen is restricted marks the end of the period of rest of the tuber and furnishes the conditions for the development of new plants. If wounded (by peeling the surface or cutting into pieces), dormant tubers will sprout, not because of a mechanical facilitation of the entry of oxygen as had been previously supposed, but because of a retardation in the entry of oxygen by the formation of dense 'wound cork' tissue that the tuber rapidly develops."

Under experimental conditions freshly harvested potatoes sprouted in seven days when held in five to 10 per cent. of oxygen under a moist condition, in nine when held in two per cent. of oxygen under a dry condition, whereas sprouting of the potatoes did not take place until 47 days after harvest, when the tubers were held in 20 per cent. of oxygen.

Acknowledging that tubers stored under ordinary farm conditions, will sprout only when the skin or periderm of the potato thickens sufficiently to allow decreased oxygen supply to the buds, what environment is most desirable if quick sprouting is needed?

In the experimental work quoted, cutting and peeling of tubers induced quicker sprouting, but, inasmuch as such methods are impracticable, other than on a very small scale, little of practical value to the farmer is learned. Other conditions which have an important bearing on the thickening or otherwise of the periderm are the effects of dry and moist storage. Moist conditions facilitate, and dry conditions retard the formation of the periderm. This is the reason given for the fact that potatoes stored under moist conditions will sprout earlier than potatoes stored under dry conditions. It would thus be possible for growers to some extent, to regulate the sprouting of their tubers by attention to storage conditions. It has been known to many of us that potatoes stored under moist conditions have sprouted comparatively quickly; some growers have used various solutions, such as nitrate of soda and sulphate of ammonia with water, and have claimed that such solutions when sprayed over the tubers have hastened sprouting. While such solutions may or may not have a beneficial effect, it would appear evident that the spraying to which the potatoes have been subjected would create a moist condition which would enable the skin to thicken sufficiently to hasten sprouting.

It is felt that many growers will be interested in the findings of the experimental work quoted; on a subject which, so far as is known, has received but little attention.

Gypsum.

ITS PLACE IN AGRICULTURE.

G. H. Burvill, Assistant Plant Nutrition Officer.

Gypsum is a compound of lime and sulphuric acid and is of relatively common occurrence in nature. Large deposits at Stassfurt, Germany, and in the United States, occur beneath rock salt deposits formed by the evaporation of enclosed bodies of sea water. In clay deposits and clay subsoils, gypsum crystals are commonly found, while in Western Australia there are extensive bodies of more or less pure gypsum associated with the large salt lake systems of the wheatbelt and the more arid inland regions. Large crystals occur in the beds of many of these lakes, while on the eastern and south eastern margins dunes and banks of finer crystals, and also of powdery gypsum sometimes called "kopi," are found. The higher grade deposits of small crystals known as *seed gypsum* are used industrially for the manufacture of plaster of Paris. In the manufacturing process the gypsum is heated and loses portion of the water it contains, known as water of crystallisation.

In agriculture, gypsum is also known as "land plaster." It has been used as a fertiliser or soil amendment since very early times and is mentioned by some of the ancient Roman and Greek writers. Many conflicting reports and opinions exist, however, concerning its general value in agriculture. In special cases definite advantages have followed its use and, no doubt, soil differences account for many of the variable results obtained with gypsum. *Its general use, therefore, cannot be recommended on all classes of soils.*

Figure 1.
General view of alkaline land at Fresno, California, on which reclamation experiments have been carried out. Photographed May, 1920, when experiments were begun.

Instances where the use of gypsum has been beneficial.

The use of gypsum in the reclamation of "black alkali" lands in America is one of the best known cases of its profitable use. Many irrigated areas in the more arid regions of U.S.A. have become more or less sterile through the accumulation of salts in the surface soil. In some cases the composition of the clay

particles is also altered by the exchange of calcium for sodium from the salts, and the resulting sodium soils will not maintain good tilth when cultivated. They are sticky and rather impervious when wet and bake hard when dry. Work at Fresno in California has shown that, while such soils can be ultimately reclaimed by careful irrigation alone, the process is much quicker if gypsum is also applied to the soil. Figures 1, 2 and 3 illustrate the type of land at Fresno, and stages in the reclamation using irrigation alone and irrigation together with heavy applications of gypsum. It will be noted that the gypsum was applied to the plot 4 (Fig. 3) at 15 tons per acre, nine tons in 1920 and six tons in 1921. The gypsum acts through replacing the sodium in the black alkali soil with calcium from the gypsum. The physical condition of the soil is improved and this allows better percolation of irrigation water and improves conditions for the roots of planted crops.

Figure 2.
Lucerne growing on plot 5 of the Fresno experiments in September, 1927. This plot had been irrigated but received no gypsum.

Figure 3.
Lucerne on plot 4 of the Fresno experiments in September, 1927. This plot had received the same irrigation as plot 5, but had also received 15 tons of gypsum per acre.
Photographs from Bulletin 455, University of California, Agric. Expt. Stn.

On many of the heavier soil types in the irrigation areas along the Murray River in New South Wales, Victoria and South Australia, dressings of gypsum are commonly given to improve the physical condition of the soils for cultivation and irrigation. Several tons per acre are usually applied on the surface, and worked in by the various cultivations. In the Sudan, also, heavy intractable clay soils which absorb irrigation water very slowly have been greatly improved by applications of gypsum up to 10 tons per acre.

Improvements in wheat yields by using gypsum have been obtained in Victoria on soils around Goroke in the western Wimmera. These soils have a sandy surface and a dense clay subsoil and, over a two year period, yields were raised from 15.7 bushels to 26.5 bushels per acre by applying 1½ tons of gypsum per acre, in addition to the usual dressing of 1 cwt. per acre of superphosphate.

Instances where no benefit has followed the use of gypsum.

Large areas in the Salmon Gums district of Western Australia have sandy surfaced soils with rather dense clay subsoils similar in general nature to the Goroke soils instanced above, but experiments carried out at Salmon Gums and Scaddan in 1938 showed no advantage from the use of gypsum at rates of one and five tons per acre.

In the drier parts of the wheatbelt of this State, bare "wind-swept" patches occur on many farms. These have been found to have salt accumulations in the surface soil and fail to maintain a good tilth after rain. On the Yilgarn Research Station the effect of gypsum was tried on an area where such patches were numerous, but the results did not indicate any conclusive advantage from the use of gypsum. Five plots receiving 5 tons of gypsum per acre, in addition to superphosphate, gave yields ranging from 5 bushels 36 lbs. to 9 bushels 4 lbs. per acre, while five other plots receiving superphosphate only gave yields ranging from 4 bushels 24 lbs. to 8 bushels 48 lbs. The increases, even if really due to the gypsum treatment and not due to chance, would not warrant the use of gypsum with the fertiliser. In subsequent years, land badly affected by smooth, bare patches, was not available for cropping, but it seems unlikely that the general use of gypsum on such wheat lands would be profitable. Individual, caked, smooth patches may possibly be improved by a dressing of gypsum if this were readily available close at hand.

It has often been stated that the application of gypsum renders potash in the soil more available to crops, but many investigations have shown no such effect on various soils and it cannot, therefore, be accepted as a general rule. In some instances gypsum may improve the availability of potash.

Gypsum is frequently recommended in older text books and leaflets for application to manure heaps to prevent losses of ammonia. The idea that it can prevent this loss is now largely discredited if the manure is allowed to dry. The use of superphosphate on manure heaps in a similar manner is probably much more valuable.

Gypsum and soil acidity or "sourness."

Although gypsum is related to quick lime and slaked lime in that it contains the same metallic element, calcium, it cannot function in correcting soil acidity or sourness in the way that quick lime and slaked lime do. In fact, it may act in the opposite direction and tend to increase soil acidity slightly, because of the greater absorption by plants of its calcium as compared with its sulphate portion.

Gypsum and superphosphate.

As stated earlier, gypsum is a compound of lime and sulphuric acid known chemically as calcium sulphate. Naturally occurring gypsum, as in the salt lake deposits, contains no phosphate and hence cannot replace superphosphate whose prime function is to supply phosphate for the crops or pastures. Calcium sulphate in gypsum is combined with water of crystallisation but, in another form known as anhydrite, it contains no water. Now, in the manufacture of superphosphate by the use of sulphuric acid on rock phosphate, the chemical process, besides making the phosphate water soluble, produces a mixture of gypsum and anhydrite; in fact, nearly half the weight of 22 per cent. superphosphate is made up of gypsum and anhydrite. Since the use of superphosphate is so general for pastures and crops in Western Australia, it follows that a considerable amount of calcium sulphate is applied annually with the superphosphate, whether it is of value on a particular soil or not. The actual amount applied will range from 40 to 60 lbs. per acre, in the case of cereal crops, up to several hundredweights per acre with potatoes, tobacco and vegetables.

Clearing muddy water.

A minor use of gypsum in agriculture is for clearing muddy water. Sprinkled over the surface of the muddy water in earth dams or tanks, it causes the suspended clay particles to settle out. For small tanks of water, 1 lb. of gypsum per 200 gallons may be used, while for a thousand cubic yard dam, about 400 lbs. of gypsum should be effective.

Worms in Sheep.

C. R. Toop, Senior Veterinary Surgeon.

The parasitic worms of sheep are widely distributed throughout Australia, constituting a source of serious economic loss to the sheep industry. These losses result from the great loss of condition which occurs in infected animals, and the failure of young sheep to thrive and make normal growth with a consequent reduction in carcase value and in the quantity and the quality of the wool produced. Furthermore, heavy infestations with worms are quite frequently responsible for serious mortalities. In Western Australia, on account of the long dry summer which is unfavourable to the development of worm eggs and larvae, these losses are not so serious as those which occur in parts of Eastern Australia which are favoured by a summer rainfall or an evenly distributed annual rainfall. Moreover, certain important parasites such as the nodule worm, which flourish under the latter climatic conditions, do not exist in this State. Notwithstanding these limitations, the losses due to worm infestation in Western Australia are quite considerable. For the most part they are sustained during the dry months of summer, but are by no means infrequent during winter in the South-Western districts.

The majority of sheep harbour some worms, but the effect upon the animal will obviously depend upon the numbers of the parasites present and in addition it will be influenced to a very considerable extent by the nutritional conditions which prevail. The presence of a few worms is of little consequence, and will produce no ill effects upon the health of the animal. A heavy infestation, on the other hand, may set up well marked symptoms of disease which may be accompanied

by heavy mortality. The nutritional conditions are of the utmost importance in relation to the effects produced. A well nourished sheep is quite often able to resist the effects of an infestation which might prove fatal in the case of a poor conditioned animal which is required to exist upon a much lower level of nutrition. The influence of nutrition is well illustrated in the outbreaks of disease associated with worm infestation which occur in this State during the summer months. The majority of the worms harboured by the sheep are picked up from the pastures during spring when the warm moist conditions which then prevail are favourable to the development of the parasites. The sheep show no ill effects while there is an abundance of succulent green available. When, however, the feed dries off and its nutritive value in consequence becomes greatly reduced the effect of the infestation becomes apparent, declaring itself in a well marked loss of condition together with the development of other more or less characteristic symptoms. The importance of maintaining sheep in good condition and hence increasing their resistance to worm infestation by the provision of improved pastures and hand feeding during the summer months cannot be over emphasised as a control measure. Under Western Australian conditions it is of the utmost importance.

The establishment of a heavy worm infection will depend upon the climatic conditions and the degree to which the pastures are contaminated by worm eggs passed out by infected sheep. Moisture is essential to the development and survival of worm eggs and larvae. As a consequence serious infestations are more likely to occur in districts which enjoy a favourable rainfall. Heavy stocking leads to heavy contamination of the pastures. Low-lying areas which remain moist and green during summer and upon which the sheep congregate in large numbers are especially dangerous in this respect. On account of these factors worm infestation may become a serious problem in the agricultural districts, particularly in areas of higher rainfall and high carrying capacity, whereas in the dry, lightly stocked pastoral areas it is a matter of no concern.

The susceptibility of sheep to worm infestation varies considerably. Lambs particularly and breeding ewes are especially susceptible and particular attention must be paid to such animals when control measures are receiving consideration. Older sheep, as the result of previous exposure to infection, develop a well marked resistance to the parasites. In breeding ewes this resistance may be broken down by the additional burden of pregnancy and lactation.

Diagnosis.

Sheep suffering from worm infestation exhibit well marked symptoms of disease. Unthriftiness and loss of condition invariably occur. When these symptoms make their appearance the presence of worms may be suspected. From a consideration of the more or less characteristic symptoms which subsequently develop, it is frequently possible to form an opinion with regard to the identity of the parasite which is actually responsible. In all cases, however, the diagnosis should be established by the post mortem examination of an affected sheep. An animal showing typical symptoms should be selected for examination. Sheep which have recently died or which are showing advanced symptoms of disease and are in extremely weak condition are not suitable subjects for examination. In such cases the majority of the worms may have been passed out and the result of the examination may in consequence be misleading. It is important that the species of worm present should be identified since this will determine the type of treatment which must subsequently be adopted. In this connection it must be recognised that sheep may harbour a considerable variety of parasites. Some of these are capable of producing serious effects ; others are completely harmless. The parasites inhabiting the digestive tract of sheep always occur in the same location and are not normally found elsewhere. The large stomach worm, for example, is always found in the fourth stomach ; the Trichostrongyles or hairworms are confined to the first 15–20 feet of the small intestine.

The digestive tract of a sheep is shown in the accompanying illustration, reference to which will enable the various portions to be recognised.

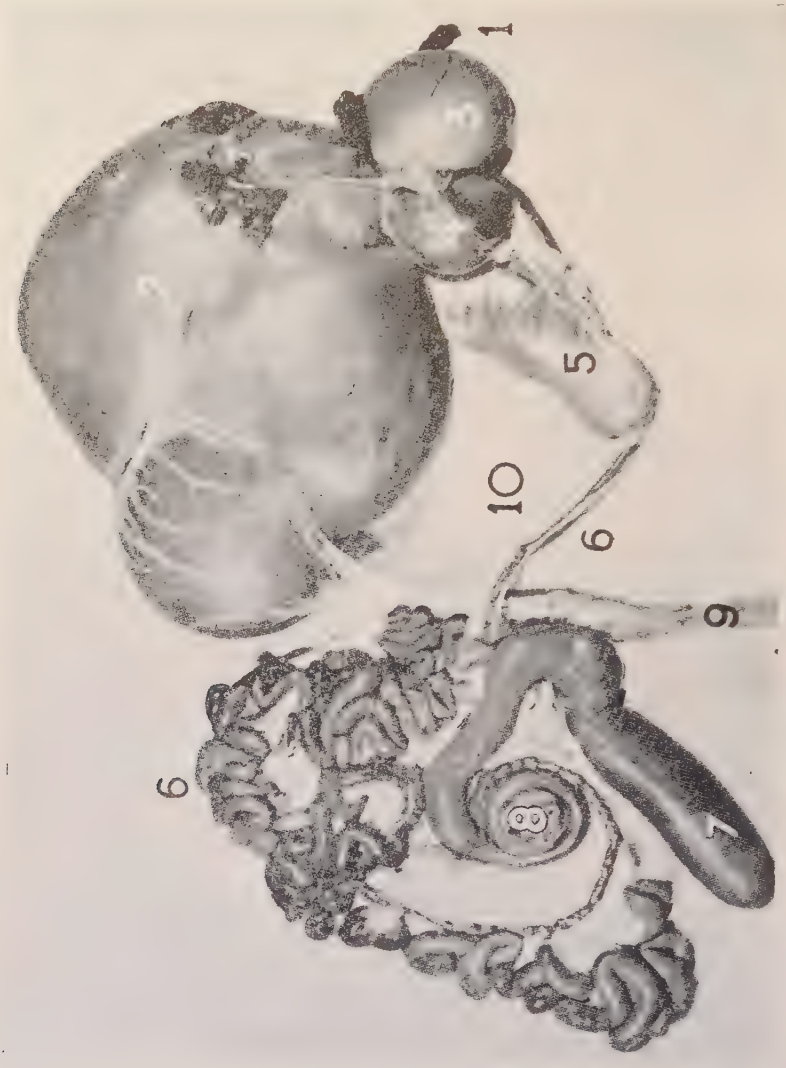

Figure 1.—Digestive Tract of Sheep.
1. Oesophagus (gullet). 2. Rumen (first stomach or paunch). 3. Reticulum (second stomach or honeycomb). 4. Omasum (third stomach or bible). 5. Abomasum (fourth stomach or rennet). 6. Small intestine (runners). 7. Caecum (blind gut). 8. Colon (crown). 9. Rectum (hind gut). 10. Omentum (Caul).
(After Clunies Ross & Gordon.)

The stomach of the sheep is large and voluminous, occupying all of the left side and portion of the right side of the abdominal cavity. It is divided into four compartments, viz., (1) the rumen or paunch ; (2) the reticulum or " honeycomb " which will be recognised because of the honeycomblike structure of its lining membrane ; (3) the omasum or " bible," so called on account of the numerous longitudinal folds or " leaves " which it contains ; (4) the abomasum or fourth stomach. In Western Australia no parasites of any kind occur in the first three stomachs of sheep. The small intestine, popularly known as the " runners," is about 80 feet in length and extends from the fourth stomach to the caecum or blind gut. The caecum in turn passes on to the large intestine which is about 15

feet in length. The first portion is much coiled and is known as the colon or "crown." The terminal portion through which the contents of the bowel are discharged to the exterior is known as the rectum or hind gut.

When conducting an examination the digestive tract should be removed from the body cavity and the intestines should be freed from their attachments. Commencing at the fourth stomach the digestive tract should be laid open with scissors and its contents, together with the lining membrane to which the parasites may be adhering, should be examined for the presence of worms. Particular attention should be paid to sections such as the fourth stomach and the first 20 feet of the small intestine in which worms capable of producing serious effects are to be found. A conclusion that the symptoms exhibited by the sheep are attributable to worm infestation will only be justified if a large number of parasites are discovered.

An alternative but less reliable method of diagnosis consists of the examination of the droppings for the presence of worm eggs. In order that such an examination may be of value samples of droppings obtained from a representative number of both healthy and affected sheep must be submitted, and the work must be supervised by a veterinarian who will be able to place a correct interpretation upon the result obtained. Cultures of the droppings must be made in order that the worm larvae which hatch from the eggs may be identified. By this means it is possible to determine the kind of worms present and to estimate the numbers in which they are present. It must, however, be emphasised that a diagnosis based upon the examination of a single sample of droppings is usually quite unreliable and may in consequence involve the sheep owner in needless worry and expense.

The worms which have been recorded in sheep in this State are described in the succeeding paragraphs. Those which are known to produce serious effects will be dealt with in some detail. The remainder will be mentioned briefly in order that they may be recognised should they be encountered.

The Large Stomach Worm or Barber's Pole Worm

(*Hæmonchus contortus*).

This is probably the most serious of the internal parasites found in sheep in Western Australia. It occurs in the abonasum or fourth stomach. The female worm is about $1\frac{1}{4}$ inches in length and shows a red and white spiral striping from

Figure 2.
Large stomach worm or Barber's pole worm (*Haemonchus contortus*) natural size.
(After F. H. S. Roberts.)

which the popular name " barber's pole " worm is derived. The males are smaller in size and uniformly red in colour. These parasites are readily visible and at post mortem may be observed moving freely in the stomach contents or adhering to its wall. The large stomach worm is a vigorous blood sucker. When the infestation is heavy large quantities of blood are withdrawn from the animal which consequently becomes affected by severe anaemia.

Symptoms:

The effects of infestation with the large stomach worm are in general most serious in young sheep and breeding ewes. All types of sheep may, however, become affected. The symptoms usually make their appearance during the summer months ; less often in early winter. Affected sheep steadily lose condition, becoming poor, unthrifty and often " pot-bellied " in appearance. Such sheep become weak and sluggish, do not move about the paddocks freely and spend less time in feeding. They are usually difficult to drive and may fall to the ground from weakness after proceeding a short distance. Upon examination the skin and mucous membranes of the mouth and eyes will be found to be extremely pale in colour. In advanced cases there may be a well marked break in the wool. Later a soft swelling appears beneath the lower jaw (" bottle jaw "). This symptom is characteristic of stomach worm infestation. Affected sheep become progressively poorer and weaker in condition and without treatment will usually succumb. Sometimes as the result of a massive and rapidly acquired infection, mortality may occur amongst sheep in fat condition, death being due to the sudden and heavy loss of blood which is withdrawn by the parasites.

Post mortem appearances:

The blood is reduced in amount and watery in appearance. The carcase is light and emaciated, the fat being replaced by gelatinous material. The abdominal cavity usually contains a quantity of clear fluid. In severe cases the liver may appear fatty and pale yellow in colour. Upon opening the fourth stomach the worms will be found in large numbers in the stomach contents and adhering to the stomach wall. It is estimated that the presence of 500 large stomach worms is necessary to produce symptoms of disease, but this will be influenced by the nutritional conditions.

Treatment:

In the treatment of flocks showing evidence of stomach worm infestation, very satisfactory results will be obtained from the administration of copper sulphate-nicotine sulphate drenches. These drugs may be employed in either two per cent. or four per cent. solutions. The two per cent. solution on account of the larger volume of the dose is recommended for the treatment of lambs and weaners. The four per cent. solution should be used for the treatment of older animals.

A four per cent. solution of copper sulphate-nicotine sulphate may be prepared according to the following formula :—

Copper sulphate (bluestone)	1 lb.
Commercial 40 per cent. nicotine sulphate (Black Leaf 40)	16 fluid ounces
Water	2½ gallons.

The copper sulphate is dissolved in the water following upon which the nicotine sulphate is added. Enamel, glass, earthenware or copper containers should be used. Metals other than copper are corroded by copper sulphate. The dosage of the four per cent. solution is as follows :—

Grown sheep	1 fluid ounce
Two-tooths	¾ ,, ,,
Lambs (8–12 months)	½ ,, ,,

The formula for the preparation of the two per cent. copper sulphate-nicotine sulphate solution is as follows :—

Copper sulphate (bluestone)	1 lb.
Commercial 40 per cent. nicotine sulphate (Black Leaf 40)	16 fluid ounces
Water	5 gallons.

The dosage of the two per cent solution is as follows :—

Grown sheep	2 fluid ounces
Two-tooths	1½ ,, ,,
Lambs (8–12 months)	1 ,, ,,
Lambs (4–8 months)	¾ ,, ,,
Lambs (under 4 months)	½ ,, ,,

The mixture should for preference be administered with a drenching syringe, or gun, many suitable types of which are now procurable. In the treatment of extremely weak sheep the dose should be reduced to that prescribed for the next lowest age group. Repeated drenching will be necessary. An interval of 14 days should elapse between the first two treatments, following upon which the treatment should be repeated at intervals of 3-4 weeks so long as this is found necessary. It may be found that a small proportion of the affected sheep do not respond satisfactorily to drenching with the copper sulphate-nicotine sulphate mixture. Such animals should be drenched with a mixture composed of two parts of carbon tetrachloride and three parts of paraffin oil. The dose of this mixture for sheep over four months old is 5 c.c. and for young lambs 2½ c.c.

In addition to treatment, the flock should be removed from infected pastures, e.g., low-lying areas which remain green and moist in summer and the level of nutrition should be improved by hand feeding or by the provision of good pasture should such be available. Hand feeding should be practised on a generous scale and if possible cereal grains such as wheat, oats or barley should be included in the ration. A rapid improvement in the condition of the sheep may not, however, be expected to occur until green feed becomes abundant. The measures which should be adopted for the prevention of infection are discussed more fully under the heading of " Prevention and Control."

The Hairworm or Black Scour Worm (*Trichostrongylus spp.*).

In Western Australia the Trichostrongyles or hairworms rank next in economic importance to the large stomach worm. These parasites inhabit the first 15-20 feet of the small intestine. They are pink in colour and are extremely small and slender,

measuring from $\frac{1}{4}$ inch to $\frac{1}{8}$ inch in length. Even when present in very large numbers the parasites, which are difficult to detect, may be overlooked unless a very careful examination is made.

Figure 3.
Hairworms. (*Trichostrongylus* spp.) natural size.
(After F. H. S. Roberts.)

Symptoms:

The hairworms are essentially parasites of young sheep. Symptoms are rarely observed in animals over 18 months old. Older sheep which have been exposed to infection as lambs subsequently develop a strong resistance to the parasite. In this State weaners are principally affected, showing symptoms of the infestation during the summer months after the feed has dried off and the nutritional conditions have become poor. Affected animals lose condition, becoming stunted in growth and unthrifty in appearance. As the disease progresses such animals become weak and sluggish and may collapse when driven. A proportion of the animals become affected by diarrhoea, the greenish-black excretions soiling the breech and the hind quarters, this condition being commonly referred to as " black scours." Unless treatment is undertaken heavy mortality may occur. The skin and mucous membranes of the mouth and eyes do not become pale or white in colour as in the case of infestation with the large stomach worm, nor is there any evidence of " bottle jaw." The fact that hairworm infestations are almost exclusively confined to weaners together with symptoms of scouring which rarely occur in sheep infected with stomach worms, will further serve to differentiate the two conditions.

Post mortem appearances:

The carcase is thin and wasted, otherwise there are no very obvious changes. Upon examining the small intestine large numbers of hairworms will be detected. A very careful examination must be made, otherwise the parasites may be overlooked. The first 20 feet of the small intestine should be laid open with scissors and the lining membrane should be closely examined in a good light ; preferably in bright sunlight. The intestine should be stretched between the fingers and held up to the light as the examination is made. If difficulty is experienced in detecting the parasites by this method the lining membrane of the intestines should be scraped with a knife and the material thus removed transferred to a shallow glass vessel and shaken with water following upon which the small thread-like worms will be observed floating in its contents. It has been estimated that the presence of at least 10,000 hairworms is necessary in order to produce serious effects. Here again this will be largely influenced by the nutritional conditions.

Treatment:

Affected animals should be drenched with a two per cent. copper sulphate-nicotine sulphate mixture in the same dosage as prescribed for sheep infected with the large stomach worm. Alternatively they may be drenched with a mixture composed of equal parts of tetrachlorethylene and paraffin oil. The dosage of this mixture is 6 c.c. for sheep from 12 to 18 months old and 4 c.c. for sheep from 4 to 8 months old. In order to obtain satisfactory results a dose of 10 c.c. of 5 per cent. copper sulphate (one ounce in one pint of water) must be given five to ten seconds before the tetrachlorethylene mixture is administered. Both of the above mentioned mixtures are reasonably effective against the hairworm, but they are not usually highly effective. Consequently repeated drenching is necessary. An interval of 14 days should elapse between the first two drenchings and thereafter the treatment should be repeated at intervals of 3-4 weeks until green feed becomes available. In addition the grazing should be supplemented by hand feeding, grain such as oats, wheat or barley being included in the ration fed. Even with regular treatment and supplementary feeding affected weaners, while able to survive, may show little improvement in condition until green feed becomes available. Hairworm infections are automatically thrown off when green feed becomes abundant.

In the control of hairworm infestation, adequate nutrition is a matter of great importance. Lambs should be drenched immediately prior to weaning and thence transferred to paddocks carrying the best available feed, these having been reserved for this purpose. Hand feeding should commence early in the summer and continue until the advent of the opening winter rains. This aspect will be discussed more fully under the heading " Prevention and Control."

The Large-Mouthed Bowel Worm (*Chabertia ovina*).

These parasites are found in the coiled portion of the colon (" crown ") and on account of their comparatively large size they are unlikely to be overlooked at post mortem. They are stout creamy-white worms measuring about three

Figure 4.
Large-mouthed bowel worm (*Chabertia ovina*) natural size.
(After Clunies Ross & Gordon.)

quarters of an inch in length and are often found adhering to the bowel wall. The economic importance of this parasite in Western Australia is still a matter of considerable doubt. Infestations with the large-mouthed bowel worm commonly

occur but they are usually associated with other parasites, e.g., large stomach worms and hairworms. The effects upon the sheep are considered to be primarily due to the latter, but it is possible that the large-mouthed bowel worm may play a contributory part. Weaners suffering from hairworm infestation may at the same time be found harbouring large numbers of large-mouthed bowel worms. If the hairworm infestation is controlled by appropriate treatment the presence of the large-mouthed bowel worms subsequently appears to become a matter of little or no concern. It has, however, been shown that this parasite is capable of inflicting considerable damage upon the bowel wall, which in consequence becomes congested and much thickened. This is accompanied by symptoms of diarrhoea in which the droppings contain much mucous and are streaked with blood, together with retarded growth, weakness and loss of condition.

Treatment:

Should the treatment of infested sheep be considered necessary, phenothiazine may be administered by the mouth in the following dosage :—

Grown sheep	¾ ounce
Sheep, 12–18 months	½ ounce
Sheep, 6–12 months	⅓ ounce
Lambs under 6 months	⅙ ounce

Phenothiazine is an insoluble powder and must be administered in the form of a suspension prepared by mixing with an equal quantity of water. The use of this drug is limited by its present high cost and the fact that drenching is somewhat difficult on account of the bulky suspension that it is necessary to administer.

Another method of treatment consists in the administration of enemata containing sodium arsenite. A concentrated stock solution is first prepared by dissolving 8 ozs. of sodium arsenite in one gallon of water. The solution for injection is prepared by adding two fluid ounces of the stock solution to three gallons of water. The quantity of solution which is required to be injected will depend upon the age and size of the sheep and is as follows :—

Grown sheep	1½–2 quarts
Sheep, 12–18 months	1–1½ quarts
Sheep, 8–12 months	1½ pints–1 quart
Sheep, 4–8 months	1–1½ pints

The solution may be administered by means of an enamel funnel to which a 3 ft. length of rubber tubing has been attached. The tubing is gently inserted into the lower bowel as far as it will go and the solution is allowed to flow in under gravity, the sheep meanwhile being help up by the hind legs. Large syringes especially manufactured for the purpose may also be employed, in which case the animal may be treated in the standing position. Before treatment, sheep should be starved for 24 hours. The injection should be given slowly. Should the animal strain during treatment the injection should be suspended until the straining has ceased.

The Large Lungworm (*Dictyocaulus filaria*).

These are long slender creamy-white worms measuring up to four inches in length. They are found in the air passages of the lungs where they will be detected without difficulty at post mortem. Infestations with the large lung worm occur

principally in the higher rainfall areas. The effects produced may be serious if the nutritional conditions are poor and the sheep are at the same time infested with stomach and small intestinal worms.

Figure 5.
Large lung worm (*Dictyocaulus filaria*) natural size.
(After Clunies Ross & Gordon.)

Symptoms:

Young sheep are most frequently affected. Coughing is a prominent symptom and is most evident on the sheep camp at night or after the sheep have been yarded. This is at first the only symptom. In lightly infested sheep the cough is strong and harsh and is not accompanied by any loss of condition. In heavily infested sheep the cough becomes soft and weak and may be altogether absent. The respiration is rapid and shallow. The animal becomes weak and sluggish and loses condition rapidly until death occurs. Suffocation resulting from the complete blockage of the air passages with the parasites is the principal cause of death. Less often pneumonia may be responsible.

Post mortem appearances:

At post mortem the parasites will be found in large numbers in the air passages of the lungs. In making the examination the trachea (wind pipe) should be split open with scissors and the finer air passages (bronchi and bronchioles) leading into it should in turn be opened. The presence of a large number of worms may result in complete blockage of the smaller air passage, resulting in the collapse of portions of the lung tissues which thus become functionless. These collapsed areas are red in colour and solid and fleshy in consistency. In addition the lungs may contain more or less extensive solid pneumonic areas which contrast sharply with the pale pink, spongy, healthy lung tissues which surround them.

Treatment:

In the treatment of affected flocks the most satisfactory results will be obtained by improving the nutritional conditions and at the same time treating the sheep for the removal of stomach and small intestinal worms. In this regard it should be remembered that serious lung worm infestations for the most part occur when

feed is scarce and when, in addition, the sheep are infested with stomach and small intestinal worms. Affected flocks should be treated by the administration of copper sulphate-nicotine sulphate drenches. They should be transferred to the best available pastures and the grazing should be supplemented by hand feeding. The removal of stomach and small intestinal worms together with adequate feeding will increase the resistance of the sheep to the lung worm, enabling it to throw off the infestation. After treatment it is important that the flock should be removed from low lying swampy areas in order to prevent reinfection.

Medicinal treatment for the purpose of removing the parasites from the lungs has not proved highly efficient. Various methods of treatment have been employed, including the injection of drugs into the wind pipe or trachea (intratracheal injections) and the inhalation of chloroform or the fumes of burning sulphur while the sheep are confined in a closed chamber. Such methods of treatment are attended by considerable risk. At best they are only partially effective and as they have little or no practical application under field conditions no useful purpose will be served by describing them here.

In the prevention of lung worm infestation, special attention should be given to the protection of lambs and young sheep. Such animals should not be allowed to graze on low lying swampy areas. High, well drained country should be reserved for them and in addition they should be adequately fed, which will greatly increase their resistance to infection.

The following parasites have also been recorded in this State but they are of little or no importance from an economic point of view. Some of these, while occurring in large numbers, are relatively harmless. In the case of others the infestations which occur are light and consequently produce no serious effets.

The Small Stomach Worm or Brown Hair Worm (*Ostertagia circumcincta*).—These are slender thread-like worms, reddish brown in colour and about half an inch in length. They occur in the fourth stomach where they will be detected when the lining membrane is carefully examined. The small stomach worm is a common parasite of sheep in Western Australia. The infestations are usually light or moderate and cause no apparent ill effects. Heavy infestations are stated to cause intermittent scouring, loss of condition and stunted growth in young sheep.

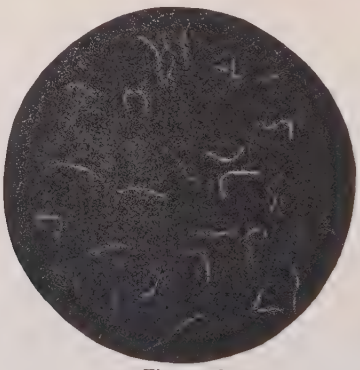

Figure 6.
Small stomach worm or brown hair worm (*Ostertagia circumcincta*) natural size.
(After Clunies Ross & Gordon.)

The Hookworm (*Bunostomum trigonocephalum*).—These are large stout reddish brown worms measuring about one inch in length. They are found in the small intestine and will be distinguished from other worms which inhabit that

portion of the digestive tract on account of their relatively large size. Hookworms are rarely met with in sheep in Western Australia and then only in very small numbers. Heavy infestations are capable of producing serious effects, the symptoms being similar to those caused by the large stomach worm.

The Thin-necked Intestinal Worm (*Nematodirus* spp.).—These parasites are found in the small intestine from 10–20 feet behind its junction with the fourth stomach. They are pink or white in colour and from $\frac{1}{2}$ to $\frac{3}{4}$ in. in length. The neck is long, slender, and coiled. Although it commonly occurs in Western Australia this parasite appears to be of little importance on account of the light infestations which occur. Serious infestations are reported in parts of Eastern Australia, where they produce symptoms of scouring and loss of condition.

Cooperia Spp.—These are small slender parasites measuring from $\frac{1}{4}$ in. to $\frac{1}{3}$ in. in length. They occur in the small intestine and will be distinguished from the hairworms because they are somewhat stouter and brighter in colour and are usually coiled. This species is rarely encountered in Western Australia and is of no economic importance.

Figure 7.
Whip worms (*Trichurus* spp.) natural size.
(After F. H. S. Roberts.)

The Whip Worm (*Trichurus* spp,).—These parasites are found in the caecum or blind gut, attaching themselves firmly to the lining membrane. They are white in colour and about 3 in. in length. The head end of the parasite is long and slender and the body by comparison short and stout—hence the popular name "whip worm." Even when present in large numbers these parasites appear to cause no ill effects.

Oesophagostomum Venulosum.—This parasite has been recorded only in the higher rainfall districts of the South-West. It is a stout, whitish worm about $\frac{1}{2}$ in. in length and is found in the caecum or blind gut. It is a relatively harmless parasite producing no ill effects upon the animal.

The Small Lung Worm (*Muellerius Capillaris*).—The presence of this parasite is indicated by the occurrence of shot-like nodules in the lung tissues. The worm itself, which inhabits the finest air passages and is small in size, is rarely detected. The small lung worm is apparently harmless. Heavily infested sheep show no evidence of ill-health.

The Sheep Tapeworm (*Moniezia* spp.). The tapeworms are found in the small intestine. They are flat ribbon-like worms measuring up to 18 feet in length and half an inch in breadth, creamy-white in colour and segmented. The head of the parasite is extremely small ; the body increases in width from the head backwards.

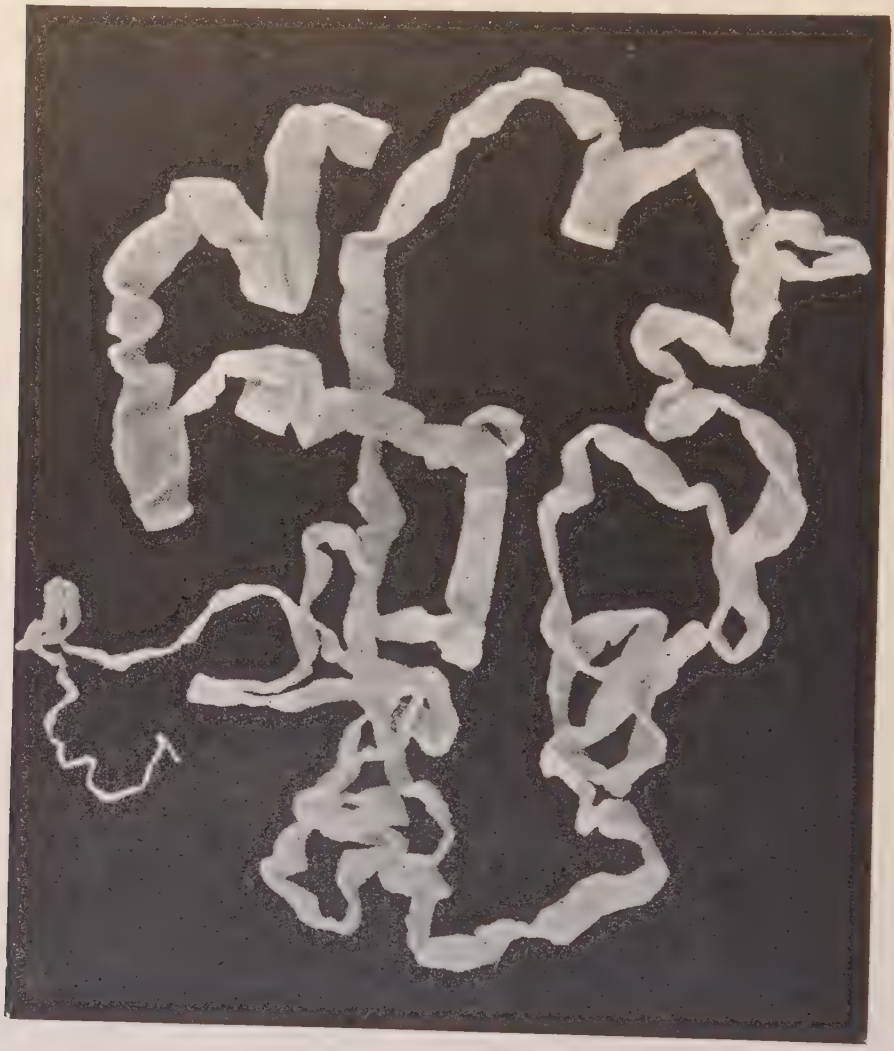

Figure 8.
The sheep tapeworm—natural size.
(After F. H. S. Roberts.)

In heavy infestations the white segments which are passed out by the sheep may be observed in the droppings. Despite their large size, the tapeworms do not usually produce any serious effects. Lambs under six months old, upon becoming heavily infested, may show evidence of stunted growth and unthriftiness accompanied by diarrhoea or constipation. In the case of older sheep the parasite is harmless. Copper sulphate-nicotine sulphate drenches are very effective for the removal of this parasite.

Life History.

A knowledge of the life history of the parasites is an essential to the application of control measures. The life cycles of the stomach and intestinal worms are in general similar. The female worms which are present in the digestive tract of the sheep produce large numbers of eggs which are passed out with the droppings and infect the pastures. Some species are prolific egg layers. A female *Haemonchus contortus* (large stomach worm) may produce 5,000-10,000 eggs daily. Within a few days the eggs hatch into larvae which, under favourable conditions of temperature and moisture, continue to grow and develop, reaching the infective stage after a further interval of 4-6 days. Infective larvae crawl up the blades of grass or herbage and are swallowed by the sheep while grazing. Upon reaching the digestive tract they develop to maturity. The infective larvae are active when the pasture is wet with rain or dew, ascending in the evening and descending in the morning. In dull rainy weather they may remain on the pastures during the whole of the day, considerably increasing the risk of infection.

The infective larvae are enclosed in a sheath and are consequently very resistant to heat and dryness, which enables them to survive on the pasture for several weeks under summer conditions. Before reaching the infective stage, larvae show little resistance to such conditions and do not survive very long. The eggs of some species such as the *Trichostrongyles* (hairworms) are highly resistant and may survive for considerably more than 12 months.

In the case of the large lung worm, the eggs are laid in the air passages of the lungs, are coughed up into the pharynx (throat) and are swallowed. In the intestine they hatch into larvae which are passed out in the droppings. On reaching the outside world the larvae continue to develop and pass on to the infective stage. Infective larvae show little tendency to migrate upwards on the pasture, but are able to survive for long periods (up to nine months) in shallow water where they are swallowed by sheep when drinking or grazing over marshy areas. Upon reaching the intestine, the larvae burrow into its wall and enter the lymph vessels by which means they are carried to the lungs, where they grow to maturity.

In the case of the tapeworms, segments containing the eggs are passed out with droppings and are consumed by an earth mite in which they hatch into larvae. These mites are swallowed by sheep while grazing and the larvae which they contain are by this means transported to the small intestine where they develop into adult tapeworms.

Prevention and Control.

In the control of worm infestation reliance should not be placed upon drenching alone. Other control measures are available which, when combined with drenching and thoroughly applied, are capable of greatly reducing the degree of infestation. The measures which may be adopted are described hereunder. While they may not be fully applicable in all cases they should as far as possible be adapted to meet the particular conditions which obtain.

Drenching.—Systematic drenching will play an essential part in any method of control. As a routine measure the flock should be drenched in the spring before the feed has dried off. In this connection it should be remembered that heavy infestations are generally acquired during the warm moist conditions of spring and that the effects become apparent in summer as the nutritive conditions become poor. Similarly in cold and wet districts in which the feed remains scarce throughout the winter months, flocks should be drenched as a routine practice during late autumn or early winter. Copper sulphate-nicotine sulphate drenches should be employed for this purpose, the flock being treated on two occasions, separated by

an interval of 14 days. This drench is highly effective against the large stomach worm and reasonably so against the hairworm, which are the most important parasites occurring in this State. Furthermore, by the removal of these parasites the resistance of the sheep to lung worm infection is greatly increased. Even better results would be obtained from the use of phenothiazine, which is very effective against both species. The high cost of this drug and the inconvenience involved in its administration, however, at present preclude its general use.

Nutrition.—Good feeding will enable the sheep to resist worm infestation and is no less important than systematic drenching as a control measure. Improved pastures should be provided, clover being especially valuable in this respect. Hand feeding should be practised during the summer months. Whenever possible, grain such as oats, wheat or barley should be incorporated in the ration at the rate of $\frac{1}{4}$–$\frac{1}{2}$ lb. per head daily. Adequate feeding is of special importance in the case of young sheep, and particularly so for the control of hairworm infestation in weaners against which parasite drenching is only partially effective.

Rotation and spelling of pastures.—If a paddock is left unstocked with sheep for a period of three months, large numbers of the worm larvae infesting the pastures will die out. Although the eggs of some species are very resistant and are able to survive lor long periods, the spelling of pastures in this manner will enormously reduce the degree of infestation. The hot dry conditions of summer are particularly effective in bringing this result about. Consequently if a system of rotation is practised whereby sheep are regularly moved to paddocks which have been spelled for two or three months, the risk of worm infestation will be greatly reduced. Even if pastures are spelled for as short a period as one month this will prove of decided value.

Burning off at the end of summer will also assist in freeing the pastures of worm eggs and larvae. Pastures which have been spelled or burned off should be reserved for the reception of lambing ewes and weaners.

Avoid low lying marshy areas.—Moist and marshy areas which remain green during summer are especially dangerous. Sheep congregate on such areas in large numbers and as a consequence the pasture becomes heavily contaminated with worm eggs and larvae. Further contamination may result from drainage from surrounding hills. The moisture which is present favours the development of eggs and larvae and the close grazing resulting from the heavy stocking further increases the risk of infestation. Similarly swamps containing shallow water which favours the development and survival of lung worm larvae should also be avoided. Such low lying and swampy areas should be fenced and provision should be made for watering from troughs.

Avoid overstocking.—Overstocking will lead to heavy contamination of the pastures and the resultant close grazing will ensure that large numbers of infective larvae are consumed by the sheep. When the provision of improved pastures results in high carrying capacity, the increased risk of worm infestation may be offset by the adoption of a system of rotation and spelling of pastures.

Protection of lambing ewes and weaners.—These animals are the most susceptible and special precautions should be taken for their protection. Ewes should be drenched shortly before lambing and then transferred to paddocks which have been spelled for three months or longer, or which have been burned off. Lambs should be drenched at the time of weaning and then transferred to paddocks which have been spelled for a similar period, and which are carrying good feed.

Paddocks intended for the reception of weaners should be closed up towards the end of winter, which will enable the above requirements to be fulfilled. In addition, lambs and young sheep should not be allowed access to marshy or swampy areas. Hand feeding should be practised during the summer. In the case of weaners it should commence early (December or January), which will enable the animals to accustom themselves to the feeders and will ensure that they do not suffer a set-back later on. The importance of adequate nutrition in the case of weaners cannot be over-emphasised. In the control and prevention of hairworm infestation it is the first line of defence.

Water Spot of Navel Oranges in Relation to the Application of White Oil Sprays and Various Other Orchard Practices.

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INTRODUCTION.

Although citrus fruits have been cultivated in Western Australia for upwards of 50 years, it is only during the last 30 years that a considerable expansion in area has occurred. The latest available figures supplied by the Government Statistician show that the production of oranges is now more than 300,000 bushels annually, and it is estimated that navel oranges comprise at least 50 per cent. of this total. Commercial production of navel oranges is confined almost entirely to the upper South-Western portion of Western Australia, and it should be clearly recognised that with the exception of one or two small areas, nowhere else in the world are citrus fruits grown under similar rainfall conditions. Elsewhere they are grown in tropical or semi-tropical regions with a summer rainfall occurring after the fruit has been harvested; in temperate regions with a well distributed rainfall rarely exceeding 10-15 inches during the harvesting period; or under irrigation in localities of very low rainfall. As compared with these areas the upper South-Western region of this State is unique, for upwards of 30 inches of rain, representing approximately 80 per cent. of the total annual precipitation, falls in the winter months of May, June, July and August, during the ripening and harvesting period. The chief citrus growing districts are widely separated within this large region and variations in local climatic conditions are responsible for differences in the time of maturity of citrus fruits grown in each district. Thus, the ripening period for navels commences in early May, in the case of the early maturing districts, and extends to late June and July in later districts, and in a few late districts fruit may hang on the tree until November in favourable seasons. Early maturing navels usually command high prices on the local market, but as the season advances the fruit becomes more plentiful, and with the advent of wet wintry weather during the months of June, July and August, the market becomes glutted with windfalls and fruit of poor keeping quality. In winters of heavy rainfall these windfalls and fruits of poor keeping quality are naturally more abundant and lead to very depressed prices. In order to avoid placing large

quantities of picked fruit on the over-supplied market, growers in the late maturing districts have always endeavoured to hold the bulk of the navel crop on the trees until later in the season, when better financial returns can be obtained. Formerly, growers regarded this practice as a profitable one, for, despite the losses sustained by windfalls and wastage, the prices subsequently obtained for the picked fruit when sold during August, September and October were much more remunerative.

ROTTING OF ORANGES ON THE TREES.

In view of the heavy rainfall which occurs throughout the citrus areas during the ripening and harvesting period, losses caused by the rotting of oranges on the trees have not been, until recent years, so serious as might be anticipated, especially in late maturing districts.

Carne (1), writing in 1923 stated "Mould (*Penicillium* spp.) is not very common on the trees, though common on fallen fruit. Where infection takes place on the tree the probable causes are injuries due to thorns or rubbing, and the collecting of water in the wounds or in the navels of navel oranges."

Since then it is true that severe losses have at times been caused by brown rot (*Phytophthora hibernalis,* Carne), but it is now well recognised by growers that this disease is readily controllable and need not be feared where the requisite control measures have been practised. Citrus pit (*Phytomonas syringae*) has also been troublesome in certain seasons, especially during abnormally wet years when climatic conditions favour the infection of pitted fruits with secondary moulds, chiefly *Penicillium* spp. (2).

During the last few years, however, many growers have reported to this Department that mature navels were rotting on the trees and dropping during the wet winter months much more than formerly, and frequently these complaints were lodged in late June and July after prolonged periods of rainy weather. Specimen oranges have been submitted by many of these growers, and in the majority of instances laboratory examination revealed the presence of citrus pit, grey mould, and *Penicillium* spp., in the rotted fruits. As these organisms are generally regarded as wound parasites, their presence in the rotted navel specimens was thought to be a natural corollary to the inevitable injuries by abrasions, leaf rubs, etc., which are of common occurrence in this State when mature citrus fruits are held on the trees during wet winter weather. Accordingly, appropriate control measures were recommended to minimise these troubles, including sanitation practices such as the removal of all rotted fruit both from the trees and the ground and the destruction of same by boiling or burying; the removal of dead wood prior to the winter rains; the pruning of any low hanging branches to allow better ventilation and drying after rain; and the spraying of the trees with Bordeaux mixture at 4:4:40 strength prior to the commencement of the winter rains, and subsequently if required during the winter months. Despite the conscientious application of these measures by some growers, results were on the whole very disappointing, and severe losses especially in late maturing districts, were still experienced during certain winters. Concluding that profitable navel orange production was no longer possible in his district, one grower in particular commenced to rework his trees over to Valencias, and several other growers contemplated doing likewise.

After the winter of 1938, accumulated departmental experience led to the belief that some factor or factors previously unconsidered must be responsible at least in part for this rotting and dropping of mature navels which recently had become so serious. In August, 1938, shortly after being appointed to the position of Plant Pathologist, the senior author, in response to an urgent request from a citrus grower, studied this problem as it occurred in the orchard.

TABLE I.

RAINFALL DATA FOR KALAMUNDA.

Yearly Average (32 years) = 4,291 points.

(100 points = 1 inch).

	1939.			1940.			1941.		
	June.	July.	Aug.	June.	July.	Aug.	June.	July.	Aug.
Total (points)	1,190	1,255	1,047	521	479	357	970	906	441
Number of wet days ...	19	21	23	17	18	14	23	28	18
Average per wet day (points)	63	60	45	31	27	25	42	32	25

	June.	July.	August.
Grand average (32 years)	826	837	698

In the Kalamunda area, a late maturing district where losses appeared to be widespread and particularly severe, it was noted that two changes in orchard practice had recently been introduced. Firstly, the application of zinc containing sprays for the control of mottle leaf which was first recognised in Western Australia in 1936 (3), and secondly the use of white oil applied in January and February for the control of white wax and other citrus infesting scale insects. The possible relation between applications of either or both of these spray materials and the incidence of the trouble was therefore considered. From a review of literature on the subject it was noticed that Parker (4) has shown that applications of zinc containing sprays to grapefruit trees affected with "mottle leaf" tend to produce fruit with a thinner and finer rind. It was considered possible, therefore, that such sprays might have had a similar effect on navel oranges when applied locally in the Kalamunda district and elsewhere, for the control of mottle leaf, rendering such fruit more liable to mechanical injury and subsequent breakdown by infection with citrus pit and moulds, during wet weather. It was noticed too, that water spot and water rot, a disease of citrus fruits particularly navels, as described by Californian workers showed many points of similarity with our local trouble both in symptoms and causation.*

*For the benefit of orchardists and other interested readers who have no access to original literature, a description of the disease published from California is included here.

According to Fawcett and co-workers (5), *water spot* is a serious rind breakdown, especially of navel oranges, during protracted periods of winter rains. Experiments have shown that the causal factor is the absorption of water, either rain or dew, by the albedo or white portion of the rind. Mature navel oranges, during long periods of rainy weather, not only become very turgid, owing to reduced transpiration and to the entrance of water from the internal conducting system, but in addition imbibe water through wounds or the natural growth cracks of the navel convolution and to a less extent through apparently uninjured surfaces. The tissue thus affected in turn affects the overlying oil glands which liberate their toxic oil internally, bringing about general breakdown of the rind in the area permeated by the water. If the period of wet weather is sufficiently protracted, almost every water-injured fruit becomes invaded by decay-producing organisms, principally blue and green moulds, which induce the stage called *water rot*. If a dry period ensues before fungi enter the water-suffused portions of the rind, no decay results and the affected tissues simply collapse and dry down, making hardened, depressed areas which are various shades of brown in colour.

In describing the early symptoms Fawcett (6) states: "Water spot of navel oranges affects most severely three locations in the rind: that surrounding the navel, that adjacent to wounds, and the shoulder portion of the stem half. Generally one of the first noticeable symptoms is a minute crackling of the cuticle which is probably due to the swelling of the underlying rind tissue when it imbibes water. On very mature fruit during and following wet weather, minute rifts and cracks in the cuticle, as seen with a hand lens, are often present without any collapse of the underlying tissue. This cracking of the cuticle is not always apparent. With continuing wet weather, any affected parts take on a water-soaked, turgid appearance and later may become discoloured and covered by dark-green to black saprophytic fungi, usually a mixture of *Cladosporium sp.* and *Alternaria sp.*"

The main conditions responsible for water spot damage of navel oranges in California are: the exposure of mature navels on the trees to prolonged rainy weather; the occurrence of injuries by abrasions, scratches and bruises, etc., and the use of oil sprays for the control of various insect pests. It is noteworthy that similar conditions are very frequently encountered in the citrus areas of Western Australia, especially in late maturing districts. In 1939, therefore, it was decided to give this matter more detailed study by field observation and experiment.

PRELIMINARY EXPERIMENT, 1939.

A preliminary experiment was therefore planned with the following main objects:—

(a) to ascertain whether the rotting of navel oranges on the trees was due either wholly or in part to water spot and water rot;
(b) to discover whether the trouble was increased by the application of either white oil* or zinc containing sprays;
(c) to determine whether Bordeaux mixture had a controlling effect.

Details of Experiment:

The experiment was conducted at Carmel in the Kalamunda district in an orchard belonging to Mr. W. M. Annetts, who previously had suffered serious losses. Unfortunately, all trees in the orchard excepting a few in one corner were sprayed with prepared white spraying oil 1:40 strength in January, 1939, prior to the planning of this experiment. Two rows, A and B, each containing eight navel orange trees, were selected, the rows being adequately separated from each other by buffer rows. Treatments were applied in March, 1939, as follows:—

Trees 1A and 1B: White spraying oil 1:40 strength applied in March.

Trees 2A and 2B: No oil applied in March.

Trees 3A and 3B: White spraying oil 1:40 strength applied in March plus zinc oxide and lime (5:2½:100).

Trees 4A and 4B: No oil applied in March.

Trees 5A and 5B: As 1A and 1B plus Bordeaux mixture 4:4:40 applied in April.

Trees 6A and 6B: As 2A and 2B plus Bordeaux mixture 4:4:40 applied in April.

Trees 7A and 7B: As 3A and 3B plus Bordeaux mixture 4:4:40 applied in April.

Trees 8A and 8B: As 4A and 4B plus Bordeaux mixture 4:4:40 applied in April.

From the rainfall data presented in Table 1 it will be seen that the precipitation during the months of June, July and August, 1939, were well above average, and actually this was one of the wettest winters ever recorded in Western Australia. Large areas were literally deluged. High winds and rain squalls characterised the unusually severe weather, resulting in railway and road washaways throughout the south-west of the State. The wind velocity frequently reached gale force and wrought havoc in urban and agricultural areas alike.

Although the percentage of rotted fruits counted on certain trees in the experiment was very high, it was soon realised that the variation exhibited by trees to which the same treatment had been applied, was much greater than anticipated. Also it became obvious that the experiment in its present form would not eliminate this factor sufficiently, and that in consequence the effects of treatments would be nullified.

It was decided, therefore, that more useful information concerning the causation of this trouble would be obtained from field studies carried out in this and other orchards in the Kalamunda district. From Table 1 it will be noticed that

*White spraying oil as used in this experiment contains 85 per cent. by weight of pale straw coloured mineral oil which has a viscosity of 80 seconds redwood at 100° F. When purchased this oil is already emulsified with about 15 per cent. of water using a special emulsifier.

during June, July and August, 1939, there were 19, 21 and 23 wet days respectively, and that the average fall per wet day was 63 points, 60 points and 45 points in each of these months. In each month prolonged periods of rainy weather occurred, e.g., in June rain fell at one period for 15 days on end. Also from the 4th to the 20th of July rain fell on all but two of the 17 days, and from the 11th August to the 29th of August rain fell on 18 out of the 19 days. This extremely wet weather accompanied also by heavy winds was ideal for the injury and subsequent rotting of mature navels on the trees and many orchards in this and other areas suffered severe losses.

Early in July, therefore, after the 15 day period of rainy weather referred to above, field studies were commenced and these were continued at intervals throughout July and August. From these observations, which are summarised below, supplemented by laboratory studies, it was concluded that much of the breakdown of navel oranges on the trees was caused by water spot, a disease which has not previously been recorded from Western Australia. It was also ascertained that the symptoms and causative factors of water spot in this State are almost identical with published accounts of the disease in California.

FIELD OBSERVATIONS, 1939.

(a) *Symptoms of Water Spot and Water Rot.*

In Western Australia, water spot of navel oranges usually affects the fruit near the navel end; somewhat less frequently at other points adjacent to slight wounds, and only very rarely at the stem end. (Plate 3.) The first recognisable symptom of the disease is the appearance of minute cracks in the cuticle of the affected area, which are readily visible with a hand lens, but not always to the naked eye. (Plate 1.) During wet weather this area soon becomes watersoaked and slightly swollen in appearance and quickly enlarges. The watersoaked appearance of affected fruits during wet weather is the most obvious initial symptom of the disease in the orchard. If dry weather now intervenes the affected area dries out, becoming rather depressed, brown in colour and leathery in texture, and the

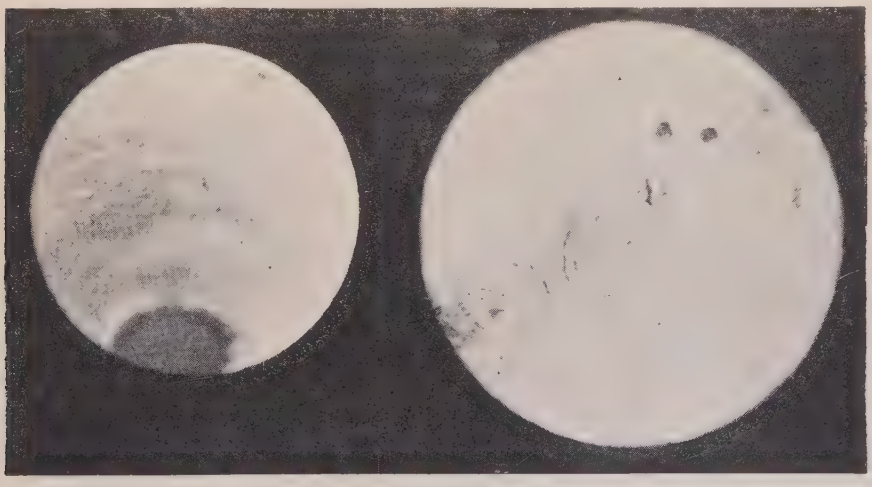

Plate 1.

Portions of oranges affected with the initial stages of water spot, showing minute cracks in the cuticle adjacent to the navel ends (x10). Fruit on left naturally affected in the orchard. Symptoms on fruit at right caused by immersion in water in laboratory.

(Micro-photographs by H. H. Kretchmar.)

surface of the lesion frequently becomes discoloured with dark saprophytic fungi. *Alternaria* spp. This stage in the development of the disease is referred to as water spot (Plate 2), and if the dry weather continues fruits so affected may hang on the tree for long periods without further breakdown. If the weather continues wet, or with a return to wet conditions some little time later, affected fruits are soon invaded with secondary organisms, chiefly blue and green moulds, or grey mould, giving rise to the condition known as water rot. (Plate 2.) The majority of fruits affected with water rot fall to the ground shortly after rotting commences, but with calm weather and the absence of further heavy rain, a small number may rot completely on the tree, eventually forming shrivelled mummies.

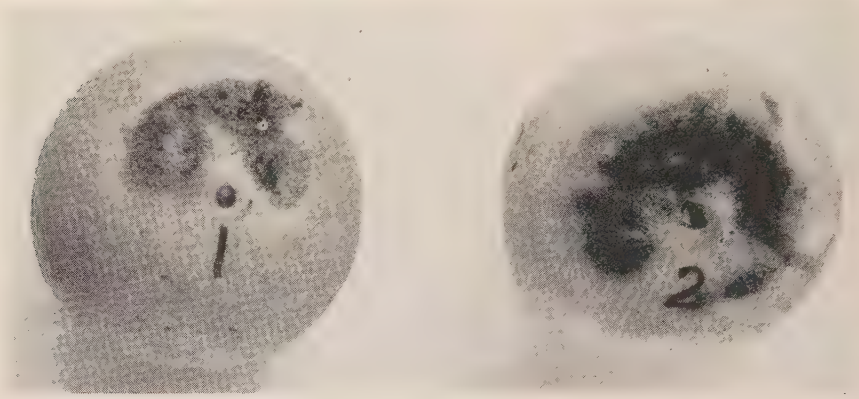

Plate 2.

Orange 1 showing water spot at navel end. The affected area is rather depressed, brown in colour and leathery in texture. The darkened areas are discolourations caused by saprophytic fungi (*Alternaria* spp.) Orange marked 2 shows the later water rot stage, in which invasion and rotting by secondary moulds has occurred.

(Photo by Govt. Photographer.)

(b) *Factors affecting the occurrence of Water Spot and Water Rot*:

Owing to extreme wetness the winter of 1939 provided a most favourable opportunity for observing the factors contributing to the development of water spot and water rot. The observations reported herewith were made at that time and have for the most part been amply confirmed either by subsequent field studies or experiments. Unless otherwise stated, therefore, they are now regarded as matters of fact.

(1) *Locality.*—Water spot has been noted in all the main citrus growing areas of this State when mature fruits are held on the trees during periods of protracted rainy weather. In early maturing districts harvesting generally commences as soon as the crop is ripe because favourable prices are usually realised at this time. In consequence these areas are not so liable to serious losses from water spot and water rot, except in seasons marked by heavy rains in early winter (May and June). On the other hand, in late maturing districts the crop does not ripen until June and July when prices show a downward tendency, and generally speaking favourable prices are only obtained for the first few pickings. As a result, therefore, only a limited proportion of the crop is marketed when first mature, the remainder being held on the trees exposed to winter rains. In seasons characterised by heavy rains in June, July and August, liability to water spot and water rot in late maturing districts is very high.

(2) *Varieties.*—In the orchard the disease has only been observed on navel oranges and mandarins. Both the Thompson's and Washington navel are susceptible to the disease, but when grown close together in the same orchard the

former variety always shows greater susceptibility. Only three varieties of mandarins affected with water spot have been noticed, namely, Beauty of Glen Retreat, Fagan's Beauty and Emperor. The first two varieties are fine skinned and appear to be more susceptible than the coarser skinned Emperor mandarin. However, the disease is noticed much less frequently on mandarins than on navels.

(3) *Maturity.*—In the orchard susceptibility appears to commence about the time the fruits are becoming mature. Susceptibility both of oranges and mandarins increases the longer the fruits are held on the trees in mature condition.

(4) *Tree susceptibility and position of fruits on the tree.*—One of the most striking facts made evident by field studies is the variation in susceptibility which is shown by different trees. It has frequently been noticed that trees of the same variety, growing in closely adjacent positions of similar soil type and apparently identical to the eye in such characteristics as size, state of health, crop carried, etc., have nevertheless exhibited marked differences in susceptibility to water spot. Many of the orchards in the Kalamunda area were planted some twenty to thirty years ago at a time when little attention had been paid to bud selection, and it is possibly due to this reason that such marked differences occur in tree susceptibility. It has been generally noticed also that fruits growing on the upper half of a susceptible tree are more seriously affected than those on the lower half, and in addition that losses in some seasons are greatest on the South-West sector of the tree where the fruit takes longer to dry after rain. This latter fact, although suspected in 1939, was not as evident in that year as during the following winter, when by comparison the winter rainfall was much lighter.

(5) *Orchard practices.*—In all orchards examined losses from water spot were much greater where white spraying oil had been applied in January or February for the control of scale insects, and in many cases these losses were estimated at more than 40 per cent. In Mr. Annett's orchard the average loss in 1939 was estimated at approximately 50 per cent. and in some portions a considerably higher figure was reached. A few trees in one corner of the orchard which had not received an application of white oil, showed noticeably less trouble, and similarly in another orchard closely adjoining Mr. Annett's property where no oil spray had been applied, losses from water spot were also much lower. It was also noticed in an orchard where scale insects had been controlled by fumigation with hydrogen cyanide gas that water spot was not nearly so prevalent as where white oil sprays had been used.

The application of Bordeaux mixture spray prior to and during the winter months was ineffective in controlling the disease and no correlation could be observed between applications of zinc containing sprays for the control of mottle leaf, and the incidence of water spot. Some correlation appeared to exist between manurial practice and the incidence of water spot. Groves which had received liberal dressings of artificial manures rich in readily available nitrogen seemed more subject to the trouble than others where the manurial applications had been restricted.

Supplementary studies, 1939:

To determine whether water spot is parasitic or non-parasitic in origin, numerous isolations were made on poured agar plates from fruits showing the early symptoms of the disease, i.e., cracking of the cuticle accompanied by a water-soaked condition of the skin. In the vast majority of instances the plates remained sterile and in the few cases where organisms developed these proved to be of secondary consequence only. It was definitely shown, however, that the early symptoms of the disease mentioned above could be induced artificially in the laboratory by immersing the navel ends of mature oranges in trays of water to a

depth of approximately one inch (see Plate 1). Such fruits, when removed from the trays and held at room temperature for a few days invariably developed lesions on the injured surfaces which were slightly depressed, brownish in colour and leathery to the touch, and identical with oranges on the trees affected with water spot. A number of oranges affected with water spot artificially induced by immersion in water were subsequently held for several weeks in the laboratory without rotting. Similarly in the orchard, fruits affected with the early stages of water spot were carefully marked and provided dry weather intervened and continued for some time, a large proportion of the fruits showed no evidence of rotting. With a return to wet conditions, however, the affected areas on the marked fruits enlarged rapidly and ultimately with continued rain, rotting by blue, green or grey mould was inevitable.

The time taken to induce water spot artificially by immersing oranges in water, varies considerably. In general, fruits which have been purposely injured by making slight abrasions, or punctures, to simulate injury in the orchard from

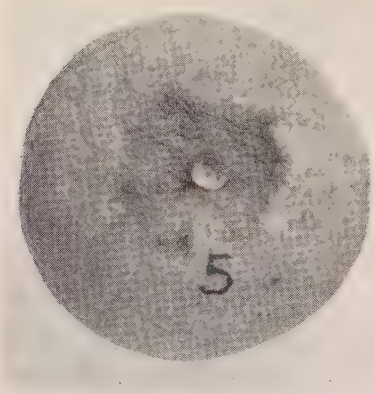

Plate 3.
Orange showing water spot at the stem end. Stem end water spot is much less common than navel end water spot in W.A.
(Photo by Govt. Photographer.)

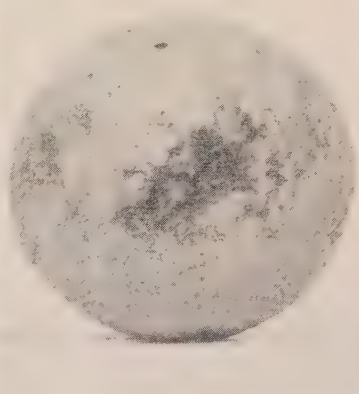

Plate 4.
Orange showing Bordeaux mixture injury which has initiated water spot.
(Photo by Govt. Photographer.)

leaf rubs, and stalk stubs, have quickly become affected in periods varying from two to four days. Fruits sprayed with white oil in January or February, on the trees, and apparently uninjured, have shown the early symptoms in periods varying from two to eight days, while unsprayed and uninjured fruits usually require a longer immersion period.

FIELD EXPERIMENTS AND OBSERVATIONS, 1940 AND 1941.

In planning a further experiment for 1940 and subsequent years it was realised that with the exception of certain orchard practices many of the observed factors which appeared to be involved in water spot causation are not readily controllable by the grower. The experiment was therefore designed with the main object of gaining more definite knowledge concerning the relations between fertiliser treatment and the use of white oil sprays, and the incidence of the disease.

Details of Experiment, 1940:

Six blocks, each containing twelve trees, were selected in a part of Mr. Annett's orchard which had been very severely affected with water spot and water rot during the previous winter. Each block was adequately separated from adjacent blocks by buffer rows. In September, 1939, all blocks received a basal dressing of mixed orchard manure and, in addition, two of the blocks (B and B1) selected at random received added sulphate of ammonia at the rate of 4 lbs. per tree, and two other blocks (A and A1), also selected at random, received added sulphate of potash at the same rate. Sulphate of potash was included as a treatment as it was thought that this substance might have an influence in correcting any possible effect of excessive soil nitrogen, and also because it might alter the texture of the rind. After careful consideration, having regard to the great differences in susceptibility shown by individual trees, it was decided to use *half trees* as units. Accordingly, the south-west halves of all the 72 trees in the six blocks were sprayed with prepared white spraying oil 1:40 strength on the 21st and 22nd February, 1940, using approximately two gallons of spray material to each half tree. Every care was taken to prevent the drift of the spray onto the unsprayed sides of each tree. In order to facilitate this a large sheet of galvanised iron was placed along the line of demarcation (running N.W. and S.E.) of each tree in turn when the spray was applied, and this ensured that only the south-west half of the tree received white oil. Prior to the advent of heavy winter rains a small sector carrying approximately 50-100 fruits was outlined with string on both the oiled and non-oiled halves of each experimental tree. In order to isolate effectively each sector for ease in subsequent counting and recording, those fruits hanging immediately around the margins of the sectors were removed at this time. Subsequently the orchard was visited at intervals during the winter months in each case after rainy weather, and the diseased fruit was removed from the sectors of each tree and counted. Also immediately prior to taking the first count of diseased fruit the total number of fruits in each sector was carefully recorded. When the final count of diseased fruit was taken the remaining sound fruits in each sector were also recorded. This final number of sound fruit, plus the number of diseased fruit removed during all counts, deducted from the original total, enabled the quantity of windfalls to be estimated.

The winter of 1940 was exceptionally dry, and it will be noticed on reference to Table 1 that the monthly precipitations for June, July and August were each well below the average. Also, less than half as much rain fell during these months as during the corresponding period in 1939.

Although no very prolonged periods of rain occurred there were 17, 18 and 14 wet days in June, July and August respectively, and thus the parts of trees sheltered from sun and winds frequently remained damp for several days on end.

The diseased fruit was removed from the experimental sectors of the trees and counted during early June and early August, and the final count was made in the middle of September. Statistical analysis of the results (see Table 2) showed that while differences due to fertiliser treatments just failed to be significant, differences due to the application of white oil were significant. In all blocks, only one per cent. of the fruit on the halves of trees receiving no oil became diseased, whereas 11 per cent. of the fruit on the other halves of the same trees became diseased following an oil spray applied early in February ($P > .05$ difference for significance $= \pm 8.2$ per cent.). The term "diseased fruit" has been used in the table above because all losses grouped in this section were not due entirely to water spot. While water spot predominated, citrus pit was also

TABLE 2.

SHOWING THE EFFECTS OF APPLICATIONS OF WHITE OIL AND FERTILISER TREATMENT ON THE INCIDENCE OF DISEASED FRUIT. THE NUMBER OF WINDFALLS IS ALSO RECORDED AS A MATTER OF INTEREST.

1940.

	Basal Manurial Dressing + Potash.				Basal Manurial Dressing + Nitrogen.				Basal Manurial Dressing only.				Effect of White Oil.			
	Blocks A and A1.				Blocks B and B1.				Blocks C and C1.				Average of all Blocks.			
	N.E. Half (No Oil).		S.W. Half (Oil).		N.E. Half (No Oil).		S.W. Half (Oil).		N.E. Half (No Oil).		S.W. Half (Oil).		N.E. Half (No Oil).		S.W. Half (Oil).	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Total Fruits (Original Count) ...	1,156	100	828	100	1,111	100	884	100	894	100	933	100	3,161	100	2,645	100
Diseased Fruit Removed from Experimental Sectors	7	1	54	6	16	1	178	20	5	1	81	9	28	1	313	11
Windfalls (Estimated)	311	26	244	29	304	27	157	18	265	30	254	27	880	28	655	25

P > ·05 – Diff for Significance = ± 8·2%

1941.

	Oil.		No Oil.		Oil.		No. Oil.		Oil.		No Oil.		Oil.		No. Oil.	
Total Fruits (Original Count) ...	1,121	100	1,120	100	1,293	100	1,282	100	853	100	959	100	3,267	100	3,361	100
Diseased Fruit Removed from Experimental Sectors	296	26	105	9	565	44	271	20	131	15	60	6	992	30	436	13
Windfalls (Estimated)	293	26	225	20	359	28	459	36	301	35	424	44	953	29	1,108	33

P > ·05 – Diff for Significance = ± 14·4%

fairly prevalent on the halves of trees receiving an oil spray. It was observed repeatedly, while counts of diseased fruit were being made, that fruits which had been sprayed with oil were apparently more liable to slight injuries from leaf rubs, and scratches and punctures caused by small twigs and dried stem stubs. As the citrus pit organism is a wound parasite, the more frequent occurrence of this disease on fruits previously sprayed with oil gives added support to this observation. It has been shown by Klotz and Basinger (7) that fresh wounds in the rind such as those caused by twig punctures and abrasions, etc., are important factors in increasing the incidence of water spot. Thus, the adverse effect of oil sprays in relation to this disease appears to be due at least in part to the greater liability to injury of oil sprayed oranges.

The vast majority of fruits affected with water spot during this winter were only slightly damaged by the disease, and in marked contrast to the development of the disease in 1939, only a small percentage of affected fruits finally succumbed to water rot. Nevertheless, the injury was sufficient to reduce the quality of even slightly affected fruits to second grade, thus lowering their market value considerably. A number of fruits affected with slight symptoms of water spot were labelled and left on the trees and in some cases, though the lesions enlarged somewhat after slight rains, no rotting had occurred up to the time the final count was made.

In order to determine whether any side or sides of the trees showed greater susceptibility to water spot than the remainder, a supplementary experiment was also conducted this year. Twelve trees were selected at random outside the experimental blocks and sprayed with white oil, 1:40 strength, on different halves. Four trees were sprayed on the N.E., S.E., S.W., and N.W. halves respectively, and each treatment was replicated three times. As a result it was shown during this winter that the S.W. half of each tree was slightly more susceptible to water spot than the remainder, and there is little doubt that this was due to the fact that this portion of the tree was more shaded and thus dried more slowly after rain.

Details of Experiment, 1941:

The experiment in this year was with one important exception similar in all essential details to that conducted in 1940. Owing to the slightly greater susceptibility to water spot of the S.W. halves of trees as shown experimentally, white oil was applied in February to the N.E. half of each experimental tree in order that any adverse effect of oil treatment should not be favoured unduly. The winter of 1941 was favourable for the occurrence of water spot as the rainfall both in June and July was above average. During the period 15th to the 30th June, 1941, rain fell on 13 out of 16 days and in July prolonged rainy weather occurred from the 10th to the 31st, rain falling on each of the 22 days. By comparison, the rainfall in August was below average. Counts of the diseased fruit in the experimental sectors of the trees were commenced in the middle of June, two counts were made during July and the final count was taken early in August, shortly after the prolonged wet weather had ceased.

Results, 1941 (*see Table* 2):

As in the previous year, statistical analysis of the results showed that differences due to fertiliser treatment just failed to reach significance, whereas significant differences were again obtained from applications of white oil despite the reversal of this treatment to the opposite and less susceptible halves of the experimental trees.

In all blocks 13 per cent. of the fruit on the south-west halves of trees to which no oil had been applied, became diseased, whereas on the north-east halves of the same trees which had received a white oil spray in February, 30 per cent. of the fruit was removed during the counts in a diseased condition ($P > .05$ difference for significance $= \pm 14.4$ per cent.). The vast majority of all affected oranges had reached the water rotted stage and many would undoubtedly have fallen from the trees in due course, had they not been removed when taking counts. The estimated average percentages of windfalls for all oiled and non-oiled sectors are therefore on the low side. It was again noticed that oil sprayed fruits were more liable to slight injuries than fruits unsprayed with oil, and also that citrus pit was more prevalent on the north-east halves of trees to which oil had been applied.

Table 3.

Counts.	Diseased Fruit removed at each Count (Percentage of Original Total).	
	S.W. Halves (No oil).	N.E. Halves (Oil).
	%	%
1st Count, 17th June, 1941	*Nil*	3
2nd Count, 1st July, 1941	*Nil*	6
3rd Count, 23rd July, 1941	3	12
4th Count, 9th August, 1941	10	9
Total	13	30

It is interesting to note in Table 3 the percentages of diseased fruit removed during the four counts from all experimental sectors. In those sectors receiving an oil spray losses commenced earlier in the season and by the time the third count was taken, i.e., within a period of five weeks, these losses totalled 21 per cent. By contrast the losses at this date on the non-oiled sectors were very slight, totalling only 3 per cent. In approximately another fortnight, however, when the fourth count was taken, the total losses on the non-oiled sectors had increased to 13 per cent. and in the period between the third and fourth counts the percentage losses were as great as in the oiled sectors. It is thus clear that while the avoidance of white oil sprays may give a longer disease-free picking period, liability to water spot increases as the oranges become more mature, and with heavy rains in late July (as in the present instance) or during August, considerable loss from water spot may result even in non-oiled trees.

In part of the orchard outside the experimental area, odd fruits here and there were noticed with symptoms of spray injury caused by applications of Bordeaux mixture. Subsequently, when examined after rain, some of these fruits developed water spot (Plate 4). Although the economic losses due to this cause were practically negligible, this is the first occasion on which Bordeaux mixture injury of citrus fruits has been noticed by the writers. Thus the matter is recorded here merely to inform growers of the probable causes and symptoms. In this instance, the spray injury was apparently caused by the occurrence of rain shortly after the spray was applied and during wet seasons favourable weather for spraying is often limited. Every care should be taken, therefore, to ensure that the bluestone has been neutralised with sufficient slaked lime prior to application, and as far as possible sprays should only be applied on fine, quick drying days.

STORAGE EXPERIMENTS, 1941.

Experiment A.—To compare the behaviour during storage of oil sprayed and non-oiled fruit.

In view of the observations which indicate that oil sprayed fruit is more susceptible to injury than non-oiled fruit on the same tree, it was thought possible that this factor might also mitigate against the successful storage of such fruits.

It has repeatedly been shown by workers who have investigated the problem of reducing wastage in stored citrus fruits, that even very slight injuries made during picking and handling are usually the major cause of any subsequent breakdown by moulds during storage. As both oil sprayed and non-oiled fruits were available from the the same trees during the progress of the experiment previously described, it was decided to take this opportunity of comparing the behaviour of these fruits during storage. Accordingly on the 4th of July, 1941, 12 cases of navel oranges were picked from six of the experimental trees. From each tree one case was picked from the oiled side and another case from the non-oiled side, and records were kept of the origin of each case of fruit. During picking and handling every endeavour was made to avoid injuring the fruit, which was then removed to the shed and sweated in cases for four days. At the end of this time it was carefully sorted and any diseased or obviously injured fruits were removed. The fruit was then loosely placed in cases which had been previously sterilised, by dipping in a proprietary fungicide, Shirlan AG, using a 1 per cent. concentration. The number of fruit in each case was kept during these operations and the cases were stacked in the packing shed and covered with a light sheet to minimise undue shrinkage of the fruit. Subsequently, the fruit in each case was inspected on four separate occasions when diseased fruits were removed and recorded. The final inspection was made on 21st September after the fruit had been held approximately 10 weeks in store. The results are shown in Table 4.

It will be seen from Table 4 that the results indicate a greater liability to wastage by moulds (*Penicillium* spp.) in the oil sprayed fruit than in non-oiled fruit from the same trees, but as this result has been obtained in one experiment only, it must be interpreted with caution. However, from the data presented it would appear that oil sprayed navels are not only more susceptible to injury on the tree, but also as a result are more liable to wastage by moulds during subequent storage. Although it was beyond the scope of this experiment to test by chemical methods for possible differences in the maturity of both lots of fruit, it can be stated that field observations showed no evidence of differences in maturity between the oil sprayed and non-oiled fruits at the time of picking.

TABLE 4.

	Original No. of Fruits. (From Six Trees)	Progressive Losses by Moulds after Storage for:—							
		2 Weeks.		4 Weeks.		7 Weeks.		11 Weeks.	
		No.	%	No.	%	No.	%	No.	%
Fruit from Oil-sprayed Side	662	8	1·2	23	3·4	42	6·2	73	11·0
Fruit from Non-oiled Side	687	1	0·1	8	1·2	16	2·3	30	4·2

Experiment B.—The problem of handling the navel orange crop in the late maturing districts of Western Australia without undue losses has always presented difficulties. Furthermore, the navel crop in these districts matures during the cold wet weather when the demand for citrus is appreciably weakened and as a result prices obtained even for cut fruit are often too low to be profitable.

Because the growers concerned have very seldom kept records of the losses occasioned by windfalls and wastage, and only recall that better prices per case are obtained by holding the fruit till September and October, it is difficult to determine what is the actual return per case of fruit produced, having regard also to the losses sustained. It seems certain that, in many cases at least, the difference between the cost of production and the financial returns secured leaves a very small margin indeed.

In view of the fact that navel oranges always command higher prices when marketed during September and October, it is obvious that some cheap method of storage to hold fruit till this time, would do much to obviate the losses caused by water spot and other wastage which occur when mature fruit is held on the tree.

Realizing this, a preliminary experiment was carried out on Mr. Annett's property at Carmel. The main object of this experiment was to ascertain whether it was possible to hold navel oranges effectively in shed storage and so minimise the losses on the trees.

It was designed to give some information—

(a) On the effect of wax as related to the keeping quality and the prevention of shrivelling of oranges kept in shed storage.

(b) On the effect of a fungicide in preventing the development of moulds in storage.

(c) As to whether wrapping of oranges in sulphite tissue paper is a factor in preventing the spread of wastage in store.

In reporting the results of this experiment at this time, we do so in order to draw the attention of growers to the possibility offered in this direction, but it should be understood that the results given are for one season's work only, and much additional data is required on the subject before definite recommendations can be made.

For the purpose of the experiment four cases of navel oranges were cut on the 12th of July from each of six trees, which had received no oil spray in February, and kept in an open shed to sweat for five days. The fruit was then sorted to remove any blemished or diseased fruits.

During all these operations the fruit was carefully handled and all possible precautions were taken to prevent injury which would inevitably lead to breakdown by moulds (*Penicillium* spp.). All cases had previously been sterilised by dipping in a one per cent. concentration of Shirlan AG.

The identity of the fruit from each tree was kept separate and the four treatments as enumerated below were replicated six times, using fruit from a single tree for each replication.

Treatments applied:—

(a) Fruit treated with a two per cent. concentration of wax emulsion (slab cream).

(b) Fruit treated with a two per cent. concentration of wax emulsion (slab cream) in which had been incorporated a one per cent. concentration of Shirlan AG.

(c) Fruit treated with a one per cent. concentration of Shirlan AG.

(d) Fruit untreated as control.

Preliminary trials showed that the application of the wax emulsion treatments in the form of a fine spray gave more uniform coverage than when the dipping method was used. Provided a fine mist spray is used, this method should be no more expensive of material than when using the dipping process where it is necessary to renew the solution from time to time.

When preparing the two per cent. wax emulsion, it was found necessary first to add to the required amount of slab cream an equal quantity of water. This should be done very slowly with constant stirring. Thereafter water may be added more quickly till the requisite dilution has been obtained. If the first stage of the mixing is not done slowly and thoroughly as described above, solid wax particles will separate out and quickly rise to the surface.

For the combination of wax emulsion with Shirlan AG, it was found that the best mix was secured by using two per cent. wax emulsion and a one per cent. concentration of the Shirlan compound. In preparing this mixture the Shirlan AG was first diluted to a one per cent. concentration in water. The necessary amount of slab cream was then emulsified as described above but by using the diluted Shirlan AG instead of the prescribed quantity of water.

This mixture appeared to give a better spread than the straight out wax emulsion.

After treatment half the number of oranges in each of the 24 cases were wrapped with sulphite tissue paper before being placed in the cases. A count of the number of fruit in each case was made and the nett weight of the fruit was recorded. The cases of treated fruit were then placed in a small chamber where the ventilation was considered ample, but not excessive, and during the ensuing 16 weeks each case was examined at intervals, when all decayed and mouldy fruits were removed and the number recorded.

After 16 weeks' storage, most of the fruit was still in good condition and none of the cases showed excessive losses. By this time, however, the palatability of the fruit was becoming affected and it was obvious that the period of useful storage was nearly finished. As a matter of interest the fruit was kept for three more weeks but by that time much of the fruit had deteriorated owing to the onset of moulds, storage spot, and loss of palatability. A percentage was still in very fair condition and this when marketed realized quite high prices.

There was no great variation between fruits from the different trees. From this experiment it was found that sulphite tissue wraps were not wholly effective in preventing the spread of moulds from rotten fruits to those adjacent and for this reason it is considered that, where possible, frequent inspections to remove rotted fruits will on the whole be cheaper and more effective.

Fruit in all treatments showed some loss in weight but the difference between the treatments in this experiment was not regarded as significant. The position of the cases in the storage chamber probably favoured the control units at the expense of the treated fruits.

Results in Table 5 show that in this experiment navel oranges were effectively held in shed storage for 16 weeks but at the end of this period the fruit rapidly deteriorated. The use of Shirlan AG as a fungicide appeared to have some effect in reducing the incidence of moulds during the storage period.

Table 5.

Treatment.	Original Number of Fruits.	Progressive Losses by Moulds after—												Losses by Storage Spot after *	
		3 Weeks.		6 Weeks.		10 Weeks.		13 Weeks.		16 Weeks.		19 Weeks.		19 Weeks.	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Wax	587	3	0·5	3	0·5	11	1·9	16	2·7	23	3·9	52	8·9	54	9·2
Wax + Shirlan AG	602	1	0·2	3	0·5	4	0·7	5	0·8	10	1·7	22	3·7	38	6·3
Shirlan AG	574	1	0·2	3	0·5	3	0·5	10	1·9	19	3·6	26	5·0	35	6·7
Control	557	2	0·4	7	1·3	13	2·3	16	2·9	34	6·1	61	11·0	26	4·7

* Storage Spot became conspicuous only after the 16th week.

The percentage of mould occurring in storage in any treatment was not unduly high and the wastage in general was very much less than would have occurred had the fruit been left on the trees. Taking into consideration that for this season the average market price ruling at the termination of even 10 weeks' storage, *i.e.* in latter part of September, was twice as high as the average price obtained at the time of picking, *i.e.*, mid-July, it will be seen that navel orange growers in the late maturing districts may find a solution to their wastage problems and have their financial returns greatly enhanced by an effective method of shed storage.

DISCUSSION OF OBSERVATIONS AND RESULTS IN RELATION TO CONTROL MEASURES.

As water spot is a non-parasitic disease, the incidence of which depends primarily on climatic conditions, it is obvious in the present state of our knowledge that complete control cannot be expected. Some measure of control may be obtained by varying various standard orchard practices, but this in turn in certain instances would lead to further complications. For example, there is no doubt that losses from water spot would be almost eliminated in most seasons were it practicable to pick and market the crop as soon as mature. It has been shown, however, that the disease is most prevalent in late maturing districts where the bulk of the navel crop is held on the trees in anticipation of better prices subsequently, and chaotic market conditions would result if entire crops from these areas were harvested as soon as mature. Also, taken over a two-year period, experimental work has shown that the average loss from water spot together with citrus pit is approximately three times as great where white oil sprays have been applied in February, contrasted with no oil spray at this time. However, losses cannot be entirely obviated merely by avoiding the use of oil sprays for when mature fruit is allowed to hang on the tree it becomes increasingly subject to the diseases mentioned, irrespective of whether oil has been used or not. Also losses from windfalls become greater as the season advances, reaching the high figure of approximately 30 per cent. on both oil-sprayed and non-oiled trees when picking is delayed until about the end of August. In the Kalamunda area the control of certain citrus infesting scale insects is also a matter of economic importance, and so far no other spray has proved so generally effective for this purpose as white oil.

Fumigation with hydrogen cyanide gas has proved very effective and both American and local experience indicate that this method of scale control properly carried out does not increase the incidence of water spot to any marked extent. The choice between these various alternatives must therefore be made by each grower according to the circumstances with which he is faced. Although no significant effect of fertiliser treatment can be shown statistically, in the experiments so far conducted, the authors, as a result of field studies, are at present of the opinion that

a correlation exists between the continued application of heavy dressings of *artificial fertilisers* rich in readily available nitrogen, and the incidence of water spot. However, the growing of leguminous cover crops during the winter months should not be neglected for this practice is a cheap and effective aid to the maintenance of both soil nitrogen and humus content at satisfactory levels.

It has been indicated that the storage experiments conducted are of a preliminary nature only and that more data is required before recommendations in this respect can be made. However, the results obtained so far are encouraging, and there is no doubt that in late maturing districts a cheap and effective method of storage for at least part of the crop which is normally left on the trees till late in the season would be attractive financially and would obviate heavy losses from windfalls and disease in certain seasons.

SUMMARY.

Commercial production of navels is almost confined in Western Australia to the upper South-West where rainfall in relation to citrus culture is unique, 30 inches or more, representing approximately 80 per cent. of the annual total, falling during the ripening and harvesting period.

Climatic variations within this large region cause differences in the time of maturity; the ripening period for navels commences in May for early districts and extends to late June and July for late maturing districts.

Early navels command high prices but by the time oranges are mature in late districts prices often show a downward tendency. In consequence, growers in these areas usually endeavour to hold the bulk of their crops on the trees in anticipation of better prices later on.

Rotting of oranges on the trees, except that due to brown rot (*Phytophthora hibernalis*, Carne), has not been as serious in the past as might be anticipated from rainfall incidence, and formerly growers in late maturing districts held navels on the trees until late September and October apparently without undue loss.

During the last few years growers in these areas have complained that mature navels were rotting on the trees, and dropping more than formerly, and this was at first attributed to citrus pit, grey mould and *Penicillium* spp., which it was thought infected the fruits through injuries.

By field studies and experiments in the Kalamunda area during the winter of 1939, which was excessively wet, it was concluded that water spot, which has hitherto not been recorded from Western Australia, was the major cause of the trouble. Symptoms of the disease and factors affecting its occurrence are described and marked similarities, both in symptoms and causation, to water spot as described from California, are noted. Laboratory experiments showed that the disease is of non-parasitic origin caused by imbibition of water by the rind, and typical symptoms of the disease were produced by immersing oranges in trays of water.

Field experiments were conducted and observations were continued during 1940 and 1941 with the objects of gaining definite knowledge concerning the effects of fertiliser treatment and white oil sprays on the incidence of water spot of navels.

In 1940, using half trees as units, it was shown that applications of white oil applied in February caused significantly greater losses from water spot on the oiled halves than the non-oiled halves, and a similar result was obtained during the following year when the oil treatments were reversed. Taken over two seasons the average loss by using white oil was three times greater than where no oil spray was applied.

During frequent inspections when the oranges were mature it was observed that fruits sprayed with oil were apparently more liable to injury than non-oiled fruits. Citrus pit was also more prevalent on the former than the latter, and as this organism is regarded as a wound parasite this observation is given added support.

Losses from water spot commenced earlier in the harvesting period on half-tree units sprayed with white oil and within a period of five weeks totalled 21 per cent., compared with three per cent. on non-oiled units. A fortnight later losses on non-oiled units had increased to 13 per cent., as against 30 per cent. for units sprayed with white oil. Thus, while the avoidance of white oil sprays may give a longer disease-free picking period, liability to water spot increases with maturity and with heavy rains in late July and August considerable loss from water spot may result even on non-oiled trees.

Although effects of fertiliser treatments on the incidence of water spot just failed to be significant, the authors as a result of field studies are at present of the opinion that a correlation exists between the continued application of heavy fertiliser dressings rich in readily available nitrogen and the incidence of water spot. However the practice of growing leguminous cover crops during winter is a cheap and effective aid to the maintenance of both soil nitrogen and humus content and is to be encouraged.

Two storage experiments were conducted in 1941. Results from one experiment indicated that oranges from tree sectors sprayed with white oil are more liable to mould wastage in storage than non-oiled fruit from the same trees. This result is thought to be due to greater susceptibility to injury of oil-sprayed fruit rather than to maturity effects. The second experiment was designed to test the effect of wax (slab cream) both with and without a fungicide (Shirlan AG), and sulphite paper wraps, on the keeping quality of stored oranges which had been obtained from trees unsprayed with white oil. In all treatments the fruit was effectively held in shed storage for 16 weeks without excessive losses, but when held three weeks longer rapid deterioration occurred After 19 weeks storage a percentage was in fair condition and realised high prices when marketed. Control measures in relation to field observations and experiments are discussed

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The authors are greatly indebted to Mr. W. Annetts of Carmel, who placed a portion of his orchard at their disposal for experimental purposes over a three-year period, and who readily gave co-operation at all times, often at much personal inconvenience.

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LITERATURE CITED.

(1) Carne, W. M. Blue mould on citrus fruit. *Dept. Agr. West. Aust.* Leaflet 114, 1923.

(2) ———. Citrus pit. *Jour. Dept. Agr. West. Aust.* 2nd Ser. 3: 378-381, 1926.

(3) Pittman, H. A. and Owen, R. C. Anthracnose and mottle leaf of citrus in Western Australia. *Jour. Dept. Agr. West. Aust.*, 2nd Ser. 13 : 137-142, 1936.

(4) Parker, E. R. Effect of zinc applications on the crop of grapefruit trees affected with mottle leaf. *Hilgardia* 11: 35-53. 1937.

(5) Fawcett, H. S., Klotz, L. J. and Haas, A. R. C. Water spot and water rot of citrus fruits. *California Citrograph* 18 : 165-175, 1933.

(6) Fawcett, H. S. Citrus diseases and their control. 461-462, 1936.

(7) Klotz, L. J. and Basinger, A. J. The influence of various types of rind injury on the incidence of water spot of navel oranges. *California Dept. Agr. Bull* 27 : 232-241, 1938.

A Survey of the Copper Content of Western Australian Pastures.

By A. B. Beck.*

SUMMARY.

Approximately 200 samples from Western Australian pastures have been analysed for copper content.

The analyses of mixed grass-clover pastures collected during the growing period seem to be satisfactory for giving an indication of the copper status of an area. Samples from areas where copper deficiency symptoms occur in stock contain under 3 parts per million (dry basis). Samples from sound areas contain over 5 p.p.m., usually 7 to 12 p.p.m. Values between 3 and 5 p.p.m. are regarded as marginal.

There is a variable fall in the copper content of a pasture as it approaches maturity. Heavy grazing of dry pastures causes a large fall.

The chemical analysis of capeweed (*Cryptostemma calendulaceum*) does not appear to give always a correct indication of the copper status of soils.

The occurrence of copper deficiency in the various soil zones of Western Australia is discussed. This deficiency is quite widespread, although in some localities it may be confined to small pockets of certain soil types. The possibility of the lateritic Darling Ranges being copper deficient is pointed out.

1. Introduction.

In 1937 Bennetts and Chapman showed that the livers and blood of lambs affected with "Gingin Rickets" or enzootic ataxia were extremely low in copper. This present investigation was originally intended to confirm and extend their observations by a study of the copper content of pastures from Gingin. As later work by the Stock and Plant Nutrition branches of the Department showed that the existence of copper deficiency was quite widespread in Western Australia, the scope of the investigation was widened in an attempt to map out both "healthy" and deficient areas by the analysis of pasture samples. The present paper makes no claim to be complete or comprehensive but is intended to present and discuss the results obtained during the period 1937-41.

As problems of animal health were being investigated, the majority of the samples analysed were mixed pastures, selected as far as possible to represent the material actually grazed by the animal. There is, however, some evidence that different species of a mixed pasture have different copper-collecting powers and on this basis, the analysis of a suitable single species would give more valuable information concerning the copper status of a particular area. For this purpose a number of botanically pure samples of capeweed (*Cryptostemma calendulaceum*) have been analysed; this was chosen as being one of the few plants growing throughout the wide range of rainfall conditions of the State.

2. The Copper Content of "Normal" Pastures.

Published data give but little indication of the range of copper content of "normal" pastures. Rusoff, Rogers and Gaddum (1937) review existing data which suggest that values between 5 and 30 parts per million (p.p.m.) copper on a moisture-free basis can be regarded as "normal." Innes and Shearer (1940)

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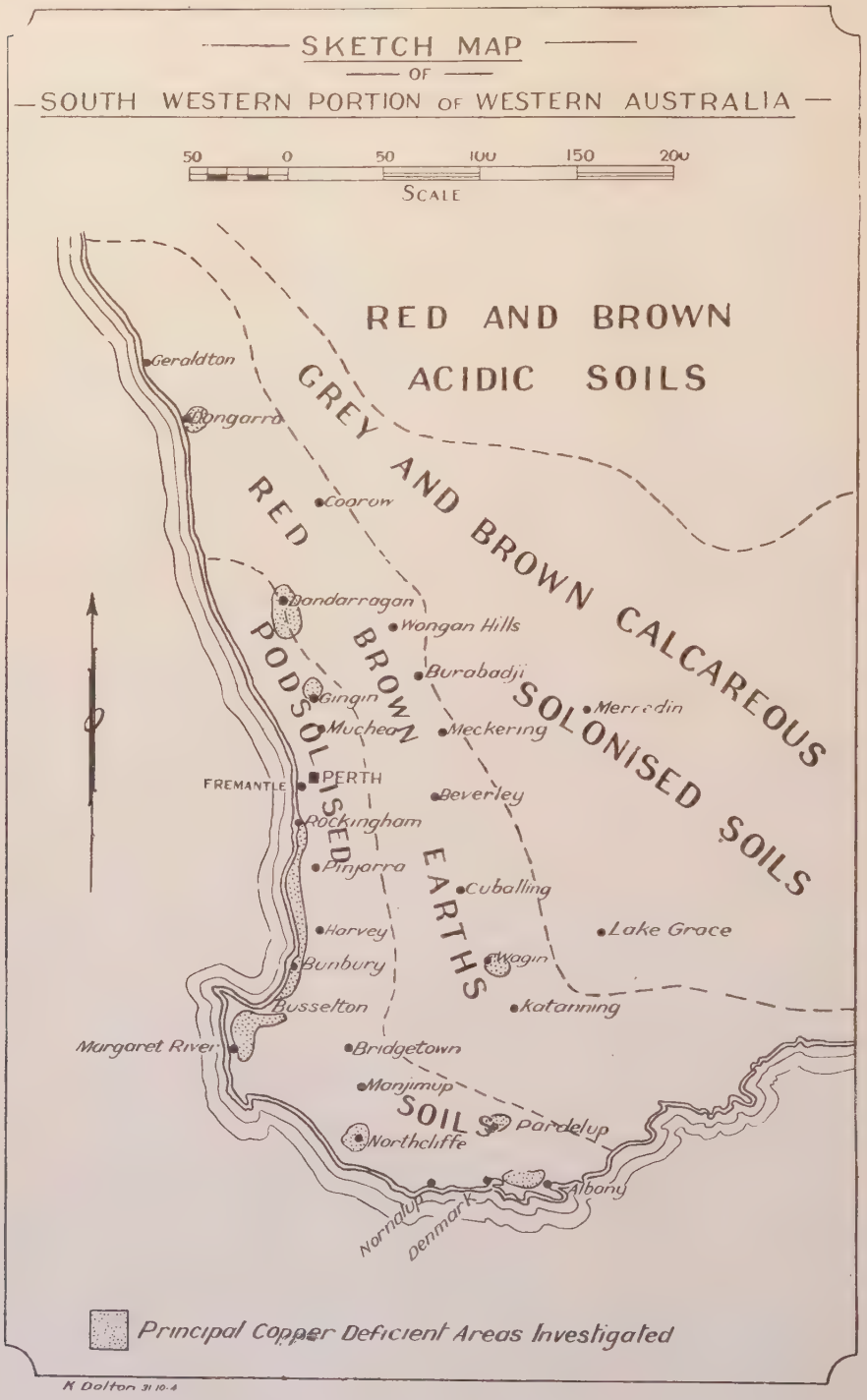
report values of 12-24 p.p.m. for apparently normal English pastures, while more recently Eden (1941) states that the copper content of Northumbrian hill-side pastures is 6-10 p.p.m.



The data set out in the Appendix have been correlated with the health of stock grazing on the pasture concerned. The following criteria have been adopted for a "normal" or "sound" pasture: (1) No ataxia in lambs or "falling disease" in cattle (Bennetts *et al.* 1941) has occurred on the property; (2) "Stringy" wool (Bennetts 1932) is not grown by sheep; and (3) sheep, lambs and cattle "do well." Due allowance has been made where copper-containing licks are fed to animals. Samples from localities where stock are not run have been omitted unless unequivocal evidence is available from the work of Teakle and his collaborators. The following tentative standards have been adopted for mixed grass-clover pastures, collected during the growing period. As in all the figures which follow, the copper content has been calculated on a moisture-free basis.

Below 3 p.p.m.	Unsound.
3 to 4 p.p.m.	Marginal: probably unsound.
4 to 5 p.p.m.	Marginal: probably sound.
Above 5 p.p.m	Sound.

"Falling disease" pastures usually contain below 2 p.p.m., while most normal Western Australian pastures contain 7-12 p.p.m. In a recent detailed study of the Denmark area, Underwood and Beck (1941) have obtained further confirmation of the hypothesis that pastures containing 3-4 p.p.m. should be classed as marginal.

It should be stressed that the above figures apply only in relation to animal health. No attempt has been made to deduce from the analyses whether or not a given pasture would be expected to give increased plant growth after the application of copper-containing fertilizers.

3. The Availability of Copper in Plant Material.

The standards of "soundness" as set out in the previous section require a certain amount of qualification. It has been observed both in this State and also in South Australia (Bull *et al.* 1938) that the incidence of ataxia in lambs is greatly increased in seasons which favour a good growth of pasture. In experimental animals at Gingin (Bennetts and Beck 1941) there was a high percentage of ataxia in 1937 and practically none in 1938. There was a tendency for a higher copper content in the 1938 pastures, but the difference was small and was not considered to be sufficient to explain the marked difference in the incidence of the disease. It would appear that there are one or more factors which operate in certain seasons and influence the availability of the plant copper to the animal. This point has been discussed more fully elsewhere (Bennetts and Beck 1941) but it should be mentioned that, at Gingin, a season favouring ataxia is usually one in which there is a rank growth of capeweed. Sheep grazing on such pastures show bad scouring which may upset the absorption of copper.

Some support for the hypothesis that the copper in rank green pastures is less available, is given by the fact that symptoms of deficiency are less marked in the summer months even although the copper content of the dry summer pastures is lower than in the winter and spring.

The experiments of Eden (1940) show that, even under conditions of high intake, copper sulphate, when mixed with the food prior to consumption, is only very slightly absorbed by sheep. It is therefore not impossible that, even under the best of conditions, only a small part of the total copper of pastures is available for use by the animals.

The results of Innes and Shearer (1940) on "Swayback" in lambs calls for brief comment. This disease is pathologically identical with ataxia, and the livers of "swayback" lambs and their mothers have a copper content similar to that encountered at Gingin. The disease also responds to copper therapy (Dunlop and Wells, 1938) but by Western Australian standards the copper content of "swayback" pastures is extremely high (14-27 p.p.m.). If these figures are confirmed it would suggest that either the copper in such pastures is not available or else the copper metabolism of the animals is deranged.

4. The Copper-collecting Powers of Different Botanical Species.

On certain newly-reclaimed sand and moor soils in Holland it was found (Hudig and Meyer, 1926) that unless copper sulphate was applied to grassland pastures, the sown species quickly disappeared leaving only Yorkshire fog (*Holcus lanatus*). Early experiments at Nornalup in this State (Baron-Hay, 1933) showed that Yorkshire fog together with *Lotus major* and Cocksfoot (*Dactylis glomerata*) were the only species which could be established on sandy peat soils now known to be copper deficient. Teakle and Morgan (1939) have made similar observations at Bornholm. Chemical analysis of samples of *Lotus major* and Yorkshire fog (Nos. 499 and 506), taken from an excellent stand on land shown to be copper deficient for potatoes, shows very low values (0.8 and 1.0 p.p.m. respectively) and supports the field evidence that both have a very low copper requirement.

Certain types of "stalling" of subterranean clover and the subsequent replacement by drooping flowered clover (*Trifolium cernuum*) are associated with the different copper requirements of the two species (Elliott, 1939). The consistently low copper content of the latter clover, and its frequent association with deficiency symptoms in stock suggest that it has a low copper requirement. Samples 475 and 476 were taken from inside and just outside a small area, about one chain in diameter, where the subterranean clover was being replaced by drooping flowered clover. The extremely low values for both samples (1.2 and 1.1 p.p.m.) suggest that the copper status of the particular area was too low to support the subterranean clover but was sufficiently high for the drooping flowered clover. The fact that a composite sample (largely subterranean clover), taken from other parts of the paddock had a rather higher content (2.9 p.p.m.) suggests that the most acute deficiency was localized in the area where the subterranean clover had "stalled."

Wheat, oat and rye plants have a low copper content even when treated with relatively large amounts of copper sulphate (Riceman *et al.* 1940 and Teakle *et al.* 1941) but under some conditions, the copper content of other species can be greatly increased by such treatment. The grass-clover pastures growing on the faintly acidic, coarse red sand at Gingin ("Whakea sand," Hosking and Greaves, 1935-36) show high values after treatment with 20 lbs. per acre bluestone, an effect which persists, although to a diminished extent, for at least three seasons. This is in marked contrast to the evidence of unpublished data from the C.S.I.R. Animal Nutrition Laboratory Field Station at Robe (South Australia). The application of up to 1 cwt. per acre bluestone causes only a relatively small increase in the copper content of various pasture species growing on this highly calcareous soil. Apparently the high pH of the soil prevents proper absorption.

The analyses of capeweed suggest that in many cases it gives figures similar to, or sometimes slightly higher than, mixed grass-clover pastures. Table 1 gives the results for samples from areas whose "soundness" is definitely known. Where the copper status is at all doubtful the figures are bracketed. Only plants collected in the preflowering or early flowering stage are included, as there is some evidence from the figures in the Appendix that very young plants may be relatively high in copper even when growing on areas known to be deficient.

TABLE 1.

Copper Content of Capeweed Samples.

A.—Western Australian Samples.

"Sound" Areas.		Deficient Areas.	
Sample No.	Cu Content.	Sample No.	Cu Content.
91	13.4	277	4.6
97	10.0	290*	2.8
294†	10.0	434	(4.8)
295	(7.8)	436†	(4.0)
304	7.6	573	4.2
305	13.5	574	2.9
430	8.4	A 76	3.0
502	13.3	A127	1.3
504	(5.2)		

B.—South Australian Samples.

A 81	12.8	A 77*†	4.9
A 82	9.3	A 78*	3.3
A117	11.8	A 79*	2.1
		A 80*	2.0

*Calcareous soil. †Rather small plants.

Although the results for the above samples seem to give a good correlation for areas whose copper status is definite, there are numerous other samples where the correlation is not clear cut. At the Wongan Hills Research Station, where blood and liver copper values for sheep are normal, one capeweed sample growing on the main soil type gave a high value (12 p.p.m.) while two other samples from poorer soil types gave very low values (3.3 and 2.2 p.p.m.). At the Merredin Research Station samples growing on a wodjil soil type gave low values (4.7 and 3.5 p.p.m.). Teakle *et al.* (1941) obtained no benefit with wheat when bluestone was applied at the rate of 15 lbs. per acre with the usual superphosphate on these soils. In fact, there was delayed early growth and substantial depression in yield showing that the rate of application of bluestone used was too high for wheat on this soil type. The effects of smaller dressings of bluestone are at present being studied. It is considered by the writer that the low values for the above capeweed samples do actually represent soils of low copper status. Besides copper deficiency it is possible that deficiency of other essential elements may also act as limiting factors. In some other cases high values have been obtained for samples from localities which might be expected to be copper deficient. The sample from "Perth Sand" (No. 282) showed a normal value (9.9 p.p.m.) and samples from two South Australian farms where ataxia occasionally occurred gave values of 5.5, 8.6 and 11.2.

Mr. T. R. Robinson has unpublished data which show that the copper absorption by capeweed may vary with the soil type. Samples taken at Gingin from areas receiving 0, 7.5 and 15 lb. bluestone per acre showed that in each case the copper content of the capeweed was identical (within the experimental error) with that of subterranean clover and Wimmera rye grass growing on the same plot. As a contrast to these results, capeweed growing on podsolised sand of low lying jarrah bush at Crawley showed a much higher copper content than subterranean

clover and Wimmera rye grass from the same area. In the present investigation samples of capeweed from the highly calcareous littoral at Rockingham gave approximately the same value as grass pastures growing on the same area.

In certain areas of the Riverina (N.S.W.), capeweed (and two other species) has been found to contain about twice the copper content of ordinary pasture plants (Australian Wool Board, 1940).

Recently Teakle, Thomas and Turton (1941) have published the analysis of seven capeweed samples from deficient and copper-treated areas. The results do not in any way correspond with those obtained in the present investigation. None of the "deficent" samples are low in copper and the treated samples tend to be lower than the non-treated. No satisfactory explanation can be offered for the different conclusions reached in the two investigations.

It has not been possible to investigate further the copper relationships of capeweed. The trend of the evidence seems to indicate that, under certain conditions which are not understood, this species is able to absorb more copper from the soil than most others. It, therefore, is not suitable as indicating the availability of copper in soils for other plants.

5. Seasonal Variation in the Copper Content of Pastures.

In a number of cases samples of mixed pasture have been taken throughout the growing season from the same area. These results are set out in Table 2.

TABLE 2.

Stage of Growth.	Wagin.				Gingin.		Merredin.
Very short	15·2	3·6	3·6	4·1	3·1	3·5	10·6
Middle of growing period ...	12·0*	3·1	3·0	4·6	2·6	3·1	6·0
Mature but not dry ...	10·3	2·5	3·5	3·7	1·7	3·8	5·0†
Dry	9·8	2·8	3·1	2·5	1·3	2·5	5·2

* Rather heavily grazed. † Almost completely dry.

The figures indicate that in general there is a rather variable fall in copper content as the plant approaches maturity

In actual practice, the seasonal variation is complicated by the effect of grazing. No data have been obtained to show the effect of heavy grazing on the copper content of green pastures, but two Gingin samples of dry pasture (Nos. 377 and 379) which had been heavily grazed showed a considerable fall in copper content. It is assumed that the sheep selectively graze the leafy material leaving the stalks and stems of lower copper content. Because of this variable drop in copper content during the growing period and the effect of grazing on the copper content of dry pasture, the writer considers that, when pasture analysis is used for diagnostic purposes, the samples preferably should be taken during the green period, and dry, grazed pastures carefully avoided.

Except where noted, the pastures listed in the Appendix had only been very lightly grazed, if at all.

6. The Distribution of Copper Deficiency in the Soil Zones of Western Australia.

The distribution of pasture copper levels in the various soil zones is set out in Table 3. Capeweed samples are included in this table.

TABLE 3.

The Copper Content of Western Australian Pastures. Distribution according to Soil Zones.

Soil Zones and Regions.	Copper Content. (Parts per Million.)									
	Unsound.		Marginal.		Sound.					
	0·0–1·9.	2·0–2·9.	3·0–3·9.	4·0–4·9.	5·0–5·9.	6·0–6·9.	7·0–7·9.	8·0–8·9.	9·0–9·9.	Above 10·0.
A.—*Podsolised Soils*—										
1. Swan Littoral Region:										
(*a*) Talus Soils	....	....	....	....	....	....	1	....	....	....
(*b*) Alluvial Soils	....	....	....	1	1	....	2	2	....	5
(*c*) Sandhill Soils	....	2	1	2	....	1	....	....	1	....
(*d*) Gingin Soils	5	13	8	2	1	1	2	....	....	....
(*e*) Falling Disease areas	15	9	5	4	1	1	1	1	....	....
2. Darling Peneplain	....	4	....	4	....	....	2	....	....	....
3. Frankland Region	3	8	10	9	3	1	1	1	1	5
B.—*Red-Brown Earths*—										
1. Irwin Region	....	2	1	....	....	....	....	2	1	2
2. Avon Region	....	4	8	3	....	1	2	....	4	7
C.—*Calcareous Solonised Soils*	....	....	1	1	2	1	1	1	....	1

The samples from the alluvial soils at the foot of the Darling Ranges were generally taken from good agricultural areas and the copper content is normal. The samples from the Harvey Irrigation Area show some of the highest figures encountered in this survey.

Abutting on to the westward side of these soils are the poor sandhill soils which in some cases produce pasture of low copper content. Much of this area is at present undeveloped agriculturally, but it will be surprising if large portions are not deficient in copper. At Muchea, maize and Sudan grass give increased growth with copper-containing fertilizers (Teakle and Burvill 1941).

The Gingin pastures are uniformly low in copper. The relation of these figures to ataxia has been discussed elsewhere (Bennetts and Beck 1941). Although no pasture samples have been obtained from the similar Cretaceous area at Dandarragan, definite evidence of copper deficiency has been reported both in stock (Bennetts and Beck 1941) and in plants (Teakle, Turton and Throssell 1940).

With two exceptions the samples from the "falling disease" areas were taken from soil types which consist essentially of a grey sandy surface with a yellowish subsoil which often contains ironstone gravel. Pasture sample No. 474 was from a brown karri loam and No. 478 was from a lateritic gravel soil. The pasture analyses show that most of the area must be regarded as being incipiently deficient in copper and in many cases, extremely so. Even properties which are regarded by local farmers as being "sound" (e.g. No. 482) have a copper status at least as low as Gingin. Field observation (Bennetts *et al.* 1941) shows the widespread occurrence of copper deficiency symptoms in stock, even where "falling disease" is not reported. The absence of "falling disease" on some properties growing pastures of extremely low copper content is ascribed to the fact that copper-containing licks are fed to the cows. Evidence from properties under close observation showed that the disease is controlled by such licks.

The lateritic soils of the Darling Ranges have been but slightly developed and so no information is available concerning a possible deficiency of copper in either plants or animals. The samples taken from plants growing on these soils all show a low copper content, and as this area is being opened up for pastures, crops and animal production the probable development of copper deficiency problems should not be overlooked.

Ataxia in lambs has been investigated at the Pardelup Prison Farm near Mount Barker. This locality was originally placed by Teakle (1937-38) in the Frankland Region but more recent investigations by him (private communication) have shown that it more appropriately belongs to the Darling Peneplain Region. The soils at Pardelup consist largely of immature granitic types and lateritic gravelly types.

The soils of the Frankland Region are probably subject to more intense leaching than those in other parts of the State. Some normal pastures have been found in this region but generally speaking the figures are low. The Denmark area has been subject to a separate investigation (Underwood and Beck 1941). These authors found that the copper status of properties where "wasting disease" occurred was "marginal." Pastures from healthy properties in the district generally showed higher copper levels. In certain areas near Walpole and Nornalup, various difficulties have been experienced in stock raising. On clinical grounds these have been associated with copper deficiency and the analyses of the limited number of pasture samples give confirmation of this.

The effect of copper fertilizers on plant growth on the soils along the Albany-Denmark railway line has been discussed by Teakle and Morgan (1939). The samples were mostly collected by Dr. Teakle and the analyses bear out the results of field trials. The pastures from the peaty sands are low in copper whereas those from the brown karri soils have a higher copper status. The sample from Kronkup was from a farm where ataxia has been reported.

The samples from Dongarra were forwarded to the writer following complaints by farmers that sheep were "not doing well." The description in the Tables in inverted commas indicate the assessment of the paddock by the farmer. The copper content of the "unsound" pastures is definitely low. Ataxia has been confirmed in this area (Bennetts, private communication) and there is some evidence of trace element deficiencies in wheat (Teakle, Thomas and Turton 1941, page 79).

The low copper content of some of the capeweed samples from Wongan Hills has been discussed in Section 4. If these figures actually represent copper deficiency, as the writer believes they do, it must be very localised as samples 511 (high) and 512 (low) were separated only by about half a mile, and under normal farming methods, sheep would not be expected to show deficiency symptoms. This also applies to the sample from Burabadji. There is no field evidence of copper deficiency in stock in these areas.

In the Meckering, Muresk and Beverley districts, basic intrusions in the granite are common, and as might be expected the pastures show no evidence of low copper levels.

The question of the fertility of "light land" at Wagin has already been discussed by Stewart and Teakle (1939). Responses to copper fertilisers were obtained by these writers and the pasture samples analysed in the present work were for the purpose of obtaining further information concerning this area. The 1939-40 series were from plots of several square chains which had been fenced with the object of taking the samples, grazing down with sheep, and then shutting

up the plots until the next sampling. This, however, was not done and with the exception of sample 493, the plots received very little grazing. The figures for this series illustrate the extreme variation of copper status with the different soil types. The second and third class land are within a mile of the first class basic red loam, yet they are definitely suboptimal and perhaps even deficient in copper. In view of the remarks in Section 4 concerning the "stalling" of subterranean clover it should be noted that an excellent stand of this clover was growing on the area where the lowest copper content of the Wagin series was recorded. Apparently the copper supply was sufficient to meet the immediate needs of the clover stand.

Samples 461, 522, and 556 from the heavy gimlet soils of the Merredin Research Station have a copper content which, judged by other figures, is on the low side. At this farm, however, sheep and lambs grow well and wool is of good quality, so it is probable that these red-brown soils produce pastures which are still "normal" but tend to approach the marginal status. This hypothesis is confirmed by the fact that liver samples from sheep on this farm show rather low values. The low copper content of the capeweed from wodjil soil has been discussed in Section 4.

7. The Value of Pasture Analysis in Delineating Areas of Copper Deficiency.

From the data obtained in this investigation it would seem that a careful interpretation of pasture analyses will give an excellent indication of areas on which copper deficiency symptoms in stock may be expected, particularly if animals are continuously grazed for a number of years.

When considering the analytical figures it is necessary to remember that the development of gross deficiency symptoms is influenced by other factors, e.g. (1) seasonal factors not fully understood; (2) whether the animals have previously had access to "sound" pastures; (3) the effect of species and breed, e.g., horses are less susceptible than sheep and cows, and the English breeds of sheep and their crosses are less susceptible to copper deficiency than merinos. In all cases, particularly where the pastures contain a "marginal" copper content, animal experiments with biochemical control are the only conclusive means of finding whether an area is "sound" or not. This will involve experiments for a period of at least two years, and preliminary pasture analyses will give a rapid method for indicating whether such experiments might be expected to give positive, negative, or uncertain results. The analysis of mixed clover-grass pastures, collected during the growing period would seem to be quite satisfactory for general diagnostic purposes; it is probable that individual clover species would also be suitable. Teakle *et al.* (1941) have reported that subterranean clover gives satisfactory results as an indicator plant for chemical analysis.

Where the soil type varies on any property, it is essential that pasture samples be taken from all soil types as a single sample might give quite misleading results.

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9. References.

Australian Wool Board (1940), *Circular,* Sept. 12th, 1940.

Baron Hay, G. K. (1933), *J. Agric.,* W. Aust., 10, 85.

Bennetts, H. W. (1932) *Aust. Vet. J.,* 8, 137.

Bennetts, H. W., and Beck, A. B. (1941), *C.S.I.R. Bull.* (in press).

Bennetts, H. W., and Beck, A. B., Harley, R., and Evans, S. T. (1941), *Aust. Vet. J.,* 17, 85.

Bennetts, H. W., and Chapman, F. E. (1937) *ibid,* 13, 138.

Bull, L. B., Marston, H. R., Murnane, D., and Lines, E. W. L. (1938), *C.S.I.R. Bull.,* 113, 23.

Dunlop, G., and Wells, H. (1938), *Vet. Rec.,* 50, 1175.

Eden, A. (1940), *J. Comp. Path. and Therap.,* 53, 90.

Eden, A. (1941), *J. Agric. Sci.,* 31, 186.

Elliott, H. G. (1939), W.A. Dept. Agric., *Departmental Report.*

Hosking, J. S., and Burvill, G. H. (1938), *C.S.I.R. Bull.,* 115.

Hosking, J. S., and Greaves, G. A. (1935-36), *J. Roy. Soc.,* W. Aust., 22, 71.

Hudig, J., and Meyer, C. (1926), *Zeit. f. Pflanz. Dung.,* 8, 14. Cited by E. J. Russell, "Soil Conditions and Plant Growth," 6th Edn., p. 103.

Innes, J. R. M., and Shearer, G. D. (1940), *J. Comp. Path and Therap.,* 53, 1.

Riceman, D. S., Donald, C. M., and Evans, S. T. (1940), *C.S.I.R. Pamphlet* 96.

Rusoff, L. L., Rogers, L. H., and Gaddum, L. W. (1937), *J. Agric, Res.,* 55, 731.

Stewart, A. M., and Teakle, L. J. H. (1939), *J. Agric.,* W. Aust., 16, 135.

Sylvester, N. D., and Lampitt, L. H. (1935), *Analyst.,* 60, 376.

Teakle, L. J. H. (1937-38), *J. Roy. Soc.,* W. Aust., 24, 123.

Teakle, L. J. H., and Burvill, G. H. (1941), *J. Agric.,* W. Aust., 18, 125.

Teakle, L. J. H., and Morgan, E. T. (1939), *ibid.,* 16, 119.

Teakle, L. J. H., Thomas, I. and Turton, A. G. (1941) *ibid,* 18, 70.

Teakle, L. J. H., and Turton, A. G., and Throssell, G. L. (1940), *ibid.* 17, 161.

Underwood, E. J., and Beck, A. B. (1941), *Aust. Vet. J.,* 17, 155.

APPENDIX.

1. *Collection of Samples and Analytical Methods.*

In collecting samples care was taken to avoid soil contamination; in the case of capeweed the samples were usually washed with water to remove adhering soil particles. After drying, samples were crushed in a Wiley mill fitted with iron screens.

Details of the analytical methods have been published elsewhere (Bennetts and Beck, 1941). In most of the samples the organic matter was destroyed by dry ashing with magnesium nitrate; in the later samples wet digestion with nitric, sulphuric and perchloric acids was used. The subsequent procedure was essentially that of Sylvester and Lampitt (1935).

All samples were analysed in duplicate. Generally with the dry ashing method, duplicate analyses were in close agreement and satisfactory recoveries of added copper were obtained. Such close agreement was not always obtained with a few highly lignified, highly siliceous samples of low copper content.

2. *Results.*

For economy of space the results have been condensed as much as possible but further details are available from the Department of Agriculture, Perth, if required.

For convenience, samples are grouped according to their soil zones (Teakle, 1937-38) and are arranged in geographical sequence. Soil details are given only when the soil type is not typical of the particular region, or when soil types vary within the locality. The names of properties are given only in cases where Teakle and his collaborators have carried out experiments.

The Gingin and Denmark results have been published eleswhere in detail but are summarized here for sake of completeness. Most of the Denmark samples were analysed by Mr. S. T. Evans.

The copper content of the pastures is expressed as parts per million, calculated on a moisture-free basis.

The following abbreviations have been used for the pasture species:—

Abbreviation.	Common Name.	Systematic Name.
Clovers—		
Clover 1	White Clover	*Trifolium repens*
,, 2	Subterranean Clover	*T. subterraneum*
,, 3	Cluster Clover	*T. glomeratum*
,, 4	Hop Clover	*T. procumbens*
,, 5	Woolly Clover	*T. tomentosum*
,, 6	Drooping Flowered Clover	*T. cernuum*
,, 7	Suckling Clover	*T. dubium*
Medic 1	Burr Medic	*Medicago denticulata*
,, 2	Goldfields Burr	*M. minima*
Grasses—		
Grass 1	Wimmera Rye Grass	*Lolium sp.*
,, 2	Perennial Rye Grass	*L. perenne*
,, 3	Cocksfoot	*Dactylis glomerata*
,, 4	Paspalum	*P. dilatatum*
,, 5	Silver Grass	*Festuca myuros*
,, 6	Barley Grass	*Hordeum murinum*
,, 7	,, ,, ...	*H. maritinum*
,, 8	Yathroo Oat	*Avena barbata*
,, 9	Yorkshire Fog	*Holcus lanatus*
,, 10	Kikuyu	*Pennisetum clandestinum*
,, 11	Prairie Grass	*Bromus unioloides*
,, 12	Madrid Brome	*B. madritensis*
,, 13	Couch Grass	*Cynodon dactylon*
Other Species—		
....	Capeweed	*Cryptostemma calendulaceum*
....	Wild Geranium	*Erodium botrys*
....	Guildford Grass	*Romulea rosea*
....	Sorrel	*Rumex Acetosella*

A.—THE ZONE OF THE GREY, YELLOW, AND RED PODSOLISED SOILS.

I.—THE SWAN LITTORAL REGION.

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
(a) *Talus Soils.*				
423	17-7-39	Armadale ...	Guildford Grass, *Bromus* sp. Clovers 2, 7	7·6

A.—THE ZONE OF THE GREY, YELLOW, AND RED PODSOLISED SOILS—*continued.*
I.—THE SWAN LITTORAL REGION—*continued.*

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
(b) *Alluvial Soils of the Flats.*				
435	7–9–39	Guildford ...	Guildford Grass	4·9
523	4–11–39	Keysbrook ...	Clover 2	7·3
563	1939 Cut	Pinjarra	Meadow Hay; Clovers 2, 7; Grass 5, 1	7·8
198	28–1–38	Harvey	Clover 1; Grasses 2, 3	8·5
199	do.	do.	Grasses 3, 4, 13	5·4
559	17–6–40	do.	Very short. Clover 2; Grasses 4, 2	14·0
560	do.	do.	Short. Grasses 2, 4; Clover 1 ...	12·4
561	do.	do.	Clovers 1, 2	12·3
562	do.	do.	Clover 2; Grasses 2, 4	8·8
305	16–9–38	Waterloo ...	Capeweed, flowering	13·5
549	5–12–39	Dardanup ...	Grass 1; various Clovers	10·2
(c) *The Sandhill Soils.*				
267	30–7–38	Mimegarra ...	Medic 1; Grasses 5, 6. Soil—Strictly an alluvial, derived from "Gingin Clay" at Dandarragan	6·3
268	do.	do. ...	As No. 267, with Capeweed	2·3
434	2–8–39	West Subiaco ...	Capeweed	4·8
170	8–11–37	do. ...	Lupin seeds	10·2
282	23–8–38	King's Park ...	Capeweed	9·9
436	9–8–39	Maida Vale ...	Capeweed. Soil—Deep white sand ...	4·0
290	5–9–38	Rockingham ...	Capeweed. Soil—Calcareous sand ...	2·8
291	do.	do. ...	Adjacent to 290. *Bromus* sp. Grasses 13, 10, 5	3·2
(d) *Falling Disease Areas.*				
A67	9–6–41	Quindalup* ...	Capeweed, small plants	3·3
314	28–9–38	Vasse*	Clover 6	3·2
317	27–9–38	Jindong* ...	Clover 6, 7; various Grasses ...	2·0
391	7–3–39	do.*	*Hypochoeris* sp; Sorrel; Grass 9 ...	1·6
412	19–6–39	do.*	Short Clover 6; Grass 9; Capeweed	1·8
A127	11–9–41	do.*	Capeweed	1·3
330	13–10–38	Yelverton ...	Clover 2	8·0
315	27–9–38	Metricup* ...	Clover 6; Grass 9; Clover 7 ...	2·2
316	do.	do.* ...	Clover 6	1·7
337	31–10–38	do.* ...	Clover 6; some Grasses	1·6
574	3–9–40	do.* ...	Capeweed	2·9
A126	6–8–41	do.* ...	Capeweed; small Plants	3·7
336	1–11–38	do. ...	Clover 2; some Grasses	3·5
343	24–11–38	do. ...	Clover 2	5·1
472	1938 Cut	do. ...	Meadow Hay; Clover 2; Grasses ...	3·6
318	27–9–38	Cowaramup* ...	Clover 6	2·4
389	8–3–39	do.* ...	Dry Grasses; Sorrel; Clover 6 ...	1·2
390	do.	do.* ...	Grass 4; Rushes; *Lotus* sp. ...	2·5
A65	9–6–41	do.* ...	Capeweed; small Plants	7·2
414	20–6–39	Margaret River ...	Capeweed; Clover 2	2·9
475	5–9–39	do. do. ...	Clover 6	1·1
476	do.	do. do. ...	Clover 2. (See note in text) ...	1·2
478	do.	do. do. ...	Clover 2; Grass 5; Capeweed ...	1·8
473	do.	Osmington ...	Clover 2; Capeweed; *Lotus* sp.; Grass 1	4·8
483	do.	do. ...	Clover 2; Grass 5	4·0
477	do.	Group 74 ...	Clover 2, 7, 6	2·1
481	do.	do. ...	Clover 6	1·4
A66	9–6–41	Witchcliffe* ...	Capeweed; small Plants	6·6
388	8–3–39	Forest Grove ...	Dry Clover 2; Grass 5	2·5
482	4–9–39	do. do. ...	As 388 (green)	2·2
387	8–3–39	do. do.* ...	Dry Grasses; Clover 6, 4; Grass 4 (green)	1·3
413	20–6–39	do. do.* ...	Capeweed; Clover 6; Grass 1 ...	1·7
415	1938 Cut	do. do.* ...	Meadow Hay	1·5
479	4–9–39	do. do.* ...	Short Clover 6; Grass 5	1·3
480	do.	do. do.* ...	Clover 6; Grass 1	1·1
573	3–9–40	do. do.* ...	Capeweed	4·2
474	5–9–39	do. do. ...	Short Clover 2; Grass 5	4·7

* Properties on which Falling Disease has occurred.

A.—THE ZONE OF THE GREY, YELLOW, AND RED PODSOLISED SOILS—*continued.*
I.—THE SWAN LITTORAL REGION—*continued.*

(e) *Gingin Cretaceous Area (Ataric).*

Group 1: "Gingin Clay."

Sample No.	Date	Copper Content.	Sample No.	Date.	Copper Content.
84	17–6–37	3·1	258	28–7–38	6·1
98	5–8–37	2·6	310	20–9–38	2·3
154	4–10–37	1·7	377	24–1–39	1·1
262	16–12–37	1·3	397	1–6–39	2·4

Mixed pastures. Predominating plants Grasses 8, 6, Medic 1. Samples 262 and 377 dry 377 and 397 heavily grazed. For soil details see Hosking and Greaves (1935–36).

Group 2: "Whakea Sand."

Sample No.	Date.	Copper Content.	Sample No.	Date.	Copper Content.
85	17–6–37	3·8	311	20–9–38	3·1
155	4–10–37	2·5	331	14–10–38	3·8
261	16–12–37	1·7	333	14–10–38	3·9
263	16–12–37	1·3	378	24–1–39	2·5
255	28–7–38	3·5	396	5–4–39	2·0
256	28–7–38	3·9	398	31–5–39	2·6
257	28–7–38	2·6	446	15–8–39	2·3
259	28–7–38	2·3	447	15–8–39	2·5
308	20–9–38	2·2	448	15–8–39	2·0

Mixed pastures. Predominating plants Grass 5, Capeweed, Clovers 7, 2, Medic 1, *Poa annua*, Grasses 12, 8, 6. Samples 261, 263 and 378 dry.

Group 3: "Whakea Sand."
Miscellaneous Samples.

Sample No.	Date.	Details.	Copper Content.
399	31–5–39	Guildford Grass	4·1
195	1937	Lupin seeds	7·9
386	1938	do.	5·0
277	11–8–38	Capeweed—Large plants	4·6
A 68	16–6–41	do. Small plants	7·1
A 76	21–7–41	do. Large plants (Same area as A 68)	3·0
A 69	16–6–41	do. Small plants	5·8
A 70	do.	do. do.	7·7

Group 4: "Whakea Sand."—Top-dressed with Copper Sulphate.

Sample No.	Date.	Copper Content.	Sample No.	Date.	Copper Content.
254	28–7–38	14·8	400	31–5–39	10·4
309	20–9–38	11·5	431	28–7–39	11·3
332	14–10–38	10·2	575	19–9–40	7·6
379	24–1–39	4·4	...	...	...

Original pasture (1937) contained 2·5 p.p.m. copper. Species similar to Group 2.
Top-dressed 20 lbs. per acre bluestone, April, 1938. Sample 379 dry and heavily grazed.

A.—THE ZONE OF THE GREY, YELLOW, AND RED PODSOLISED SOILS—*continued.*

II.—DARLING PENEPLAIN REGION.

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
514	27–9–39	Bindoon	Chittering Valley: Grasses and Clovers. Soil—Alluvial red sandy loam	6·9
508	26–9–39	Beechina ...	Short growth. Clovers 2, 3 ; Capeweed	4·1
509	do.	Wooroloo ...	Clover 2 ; Grass 5	2·7
421	17–7–39	Karragullen ...	Capeweed	2·7
422	do.	do. ...	Clover 2 ; Grasses ; Capeweed ...	4·0
497	20–9–39	Dwalganup ...	Clover 2	4·3
304	16–9–38	Bridgetown ...	Capeweed. Soil—Heavy red loam ...	7·6
634	12–9–40	Pardelup ...	Clover 2 ; Grasses	2·9
635	do.	do. ...	Clovers 7, 6 ; Grasses 5, 1	2·8
633	do.	do. ...	Clover 7 ; Grass 5	4·4

All samples except Nos. 304 and 514 were from lateritic gravel soils.

III.—FRANKLAND REGION.

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
502	19–9–39	Jardee	Capeweed	13·3
539	9–11–39	Northcliffe ...	Small Clovers ; Grasses	2·1
501	19–9–39	Walpole	Capeweed	8·0
550	14–12–39	do.	Grasses ; Clover 7	2·8
516	17–9–39	Nornalup ...	Clovers 6, 7 ; Grasses	1·8
499	18–9–39	Young's Siding ...	K. Martin's *Lotus major*. Soil—Black peaty sand	0·8
506	do.	do. do.	Grass 9, adjacent to No. 499 ...	1·0
498	do.	Bornholm ...	J. Wolfe's. Grass 2 ; Clover 2. Soil—Karri slope	10·2
503	do.	do. ...	J. Wolfe's. Grass 9. Soil—Peaty sand	2·4
504	do.	Horton's Siding	Cake Bros. Capeweed. Soil—Brown karri slope	5·2
432	31–7–39	Kronkup ...	Medic 1 ; Grasses 11, 1	3·0
500	18–9–39	Torbay	Rutherford's. Clover 2 ; Grass 9. Soil—Peaty sand	4·5
505	do.	do.	Grayson's. *Medicago* spp., *Sonchus* sp., annual grasses. Soil—Brown karri slope	7·9

Denmark Pasture Samples—

(a) From experimental holding, Wakundup soil type (Hosking & Burvill, 1938) : 8 samples 23rd March, 1939, to 12th December, 1940. Range 2·9–4·4, Mean 3·7 p.p.m.

(b) From other properties on Wakundup soil : 14 samples, 1937–1940. Range 2·2–6·5, Mean 3·7 p.p.m.

(c) From properties on Scotsdale gravelly loam and alluvial soils : 7 samples, 1937–1939. Range 4·3–22·2, Mean 9·9 p.p.m.

B.—THE ZONE OF THE RED BROWN EARTHS.

I. IRWIN REGION.

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
178	26–11–37	Greenough Flats	Lupin Seeds	11·5
453	23–8–39	Dongarra ...	Capeweed; Grasses 6, 5; Medic 1. "Sound Country"	8·9
454	do.	do. ...	Capeweed and various small Clovers. "Sound Country"	8·8
455	do.	do. ...	Grasses and Medic 1. "Sound Country"	10·6
456	do.	do. ...	Grasses 6, 5; small Clovers. "Possibly Sound"	3·2
457	do.	do. ...	Grass 6; Medic 1. "Probably Unsound"	2·9
458	do.	do. ...	Grass 6. "Probably Unsound" ...	2·2
218	3–5–38	Coorow	Grass 6; very short	9·5
233	18–5–38	do.	Grass 6; short	11·2

II. AVON REGION.

511	26–9–39	Wongan Hills Research Station	Capeweed. *Soil*—Tamar country, greyish sand, clay subsoil	12·0
512	do.	do. do.	Capeweed. *Soil*—Poorer smokebush country, yellow sand, clay and gravel subsoil	2·2
513	do.	do. do.	Capeweed. *Soil*—Poor mallee country, light grey sand, gravel subsoil	3·3
510	do.	Burabadji ...	Capeweed	4·4
97	28–7–37	Meckering ...	Capeweed	10·0
274	9–8–38	Muresk	Clover 2; Capeweed; Grasses ...	9·5
275	do.	do.	*Stipa* sp.; Grasses 5, 6	9·3
91	22–7–37	Beverley ...	Capeweed	13·4
249	14–7–38	do. ...	Grass 7	7·5
276	10–8–38	do. ...	Clover 2; Wild Geranium; Capeweed; Grasses	9·0
294	13–9–38	Cuballing ...	Capeweed	10·0
295	do.	Wagin	Capeweed. *Soil*—Light grey sand, clay subsoil	7·8
296	do.	do.	Clover 2; Wild Geranium. *Soil*—Light gritty granitic	6·7

WAGIN SERIES, 1939–40.

Date.	Group 1.		Group 2.		Group 3.		Group 4.	
	Sample No.	Copper Content.	Sample No.	Copper Content.	Sample No.	Copper Content.	Sample No.	Copper Content.
22–8–39 ...	451	15·2	450	3·6	449	3·6	452	4·1
19–9–39 ...	493	12·0	494	3·1	496	3·0	495	4·6
24–10–39 ...	519	10·3	517	2·5	520	3·5	518	3·7
14–3–40 ...	552	9·8	555	2·8	553	3·1	554	2·5

All samples dry on 14th March, 1940.

Group 1: "First Class Country."—Red brown loam on diorite ridge.
Pasture Species.—Grasses 6, 7, 12; Capeweed; Clovers 3, 4.
Sample 493 rather heavily grazed.

Group 2: "Second Class Country."—Light gritty soil.
Pasture Species.—Clover 2; Wild Geranium; Clovers 3, 5.

Group 3: "Second Class Country."—Light grey sandy surface, clay subsoil.
Pasture Species.—Clover 5; Grasses 1, 5.

Group 4: "Third Class Country."—Yellowish grey sand, gravel subsoil; original vegetation mallet, mallee, and poor wandoo.
Pasture Species.—Clovers 3, 5; Capeweed; Grass 5; some Clovers 2, 4.

C.—THE ZONE OF THE GREY AND BROWN CALCAREOUS SOLONISED SOILS.

Sample No.	Date Sampled.	Locality.	Details.	Copper Content.
283	24–8–38	Lake Grace ...	Grass 6	7·0
430	24–7–39	Merredin Research Station	Capeweed. *Soil*—Brown sandy clay loam	8·4
429	do.	do. do.	Short Grass 6. *Soil* as above ...	10·6
461	30–8–39	do. do.	As No. 429 with Medic 2, 1	6·0
522	3–11–39	do. do.	As No. 429: Dry	5·0
556	27–3–40	do. do.	As No. 429: Dry	5·2
427	24–7–39	do. do.	Capeweed. Wodjil soil	4·7
459	30–8–39	do. do.	Capeweed. Wodjil soil	3·5

Contagious Abortion-Free Herds.

The following herds have been declared free from contagious abortion, in accordance with the requirements of the scheme for the certifying of herds abortion-free, and unless otherwise declared the certificate remains in force until the date shown in respect of each herd:—

No.	Owner.	No. of Cattle Tested.	Date of Expiry.
			1942.
1	Agricultural College, Muresk	40	25th November
2	R. J. & A. J. Marshall, Denmark	29	25th November
3	W. A. Beaney, Mt. Stafford, Denmark	12	4th March
4	W. J. Deal, Scotsdale, Denmark	17	4th March
5	Grace H. Burnside, Burnside, Nornalup	44	24th March
6	A. J. Allen, Denmark	22	5th May
7	J. Haire, Scotsdale, Denmark	35	14th May
8	W. Middleton, Denmark	30	15th May
9	P. Berridge, Scotsdale, Denmark	36	28th July

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.